PRODUCTION AND EVALUATION OF SAFETY ASSURANCE SOFTWARE FOR PROCESS INDUSTRIAL SITES IN NEW ZEALAND

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ABSTRACT

With a rapidly changing environment of industrial safety legislation in New Zealand, all of the country's process industries will be required to appraise the hazards on their sites by 1993. Currently, overseas techniques are available, but their complexity, expense and data requirements make them inappropriate for most New Zealand industry. In this project, a methodology for hazard appraisal was designed to analyse and quantify hazards on process sites. The methodology was then encoded into software for ease of application. To be useful for the wide range of New Zealand industry, the software had to be easy to use, able to run using a minimum of crude data and able to run on inexpensive hardware.

The software was produced and found to give valid results from the crude data used. When its results were compared to those from an analysis using an internationally recognised method, they were found to be within the limits of expectation, considering the fundamental differences in approach. While the internationally accepted method was seen to be more reliable, the project method was found to give realistic rankings, that would be useful to a wide range of New Zealand Industry. The method of rapid ranking used would highlight potentially hazardous areas on a site and help raise the awareness of industrial hazards in the users of the method. There were several modifications specified, whose application to the project software would improve the quality of results.

1.0 INTRODUCTION

1.1 General Introduction

Over the last decade, there have been many changes in the quality and application of New Zealand's industrial safety. One of the key areas of change has been the revision of New Zealand's industrial safety legislation. These developments have occurred through changes in government, developments overseas, but the most significant factor has been changes in New Zealand industry.

With the advent of the Think Big energy projects in the early eighties, New Zealand experienced an unparalleled development of large industrial installations. At this time, overseas engineering consultants involved in these projects expressed concern that while some safety legislation existed that would cover the design and operation of large and complex plants, it was not comprehensive, nor was it able to deal effectively with the large-scale processing of hazardous substances occurring in these plants.

In 1983, the Accident Compensation Corporation (then Commission) initiated discussions between the Departments of Labour and Health and the Ministries of Energy and Transport, as the agencies responsible for industrial safety. The aim of these discussions were to develop the basis of hazard evaluation. Hazard analysis had been developed overseas in the years following the Flixborough disaster in 1974 (Lees 1980) and had been employed by Liquigas Ltd to evaluate the safety levels of its proposed operations with bulk LPG (Liquid Fuels Trust Board, 1982). As a result of these discussions, it was concluded that hazards surveys for new projects should be a part of the Environmental Impact Report and that safety audit procedures covering the commissioning of new plants should be invoked immediately by the Department of Labour.

Since 1983, several other government committees with similar representation have discussed further, the implementation of hazard assessments into the operation of major industries. Parallel to this, these committees discussed changes necessary in New Zealand's industrial safety legislation to bring it all under one authority, as recommended by Walker (1981) and earlier commissions of inquiry (New Zealand Commission For Inquiry, 1975). It was felt that the best interests of the worker in New Zealand were not being served by the segmentation of the country's safety legislation. It was also considered that proposed hazard appraisal legislation could only be made pursuant to one encompassing piece of legislation because of the diversity of expertise and statutory coverage required. Work on the hazard appraisal legislation continued in preparation for this new Act.

In 1987 the first draft piece of legislation requiring major industrial installations to carry out hazard analysis was prepared and circulated widely for comment. Subsequent drafts attempted to bring New Zealand in line with the Control of Industrial Major Accident Hazards Regulations (Health and Safety Executive, 1985), which was similar legislation enacted in the United Kingdom . This was an effort to reflect a successful overseas practice in legislating requirements for formal industrial hazard appraisal. In the years that followed, revised hazard appraisal drafts were circulated, each with minor changes in their accent. to reflect the changing attitudes on compulsory hazard appraisal.

The Occupational Safety and Health (OSH) service of the Department of Labour came into existence in 1988. It was one of five business units with the Department of Labour that had been split into a discrete organisation. This change was intended to streamline the operations of those organisations and raise their independent profiles within the community. The operational arm of the OSH service is represented by its inspectorate, which checks compliance with the enacted legislation, investigate accidents and bring prosecutions where breaches of legislation have occurred.

In 1989, the then Labour government introduced into Parliament, the Occupational Safety and Health Bill. This was the first attempt to have one Act empowering one authority. The Bill was not enacted before the change in government in 1990. The incoming government recognised the need for a revision in industrial safety and health legislation, but wished to put into place legislation that fitted its philosophy of deregulation and introduced a new Bill. In October, 1992 the new Health and Safety in Employment Act, 1992 (Parliamentary Counsel Office, 1992b) received royal ascent and was enacted. Instead of a factory owner with a health and safety problem having to deal with different agencies empowered by different pieces of legislation with the potential for conflicting requirements, the OSH service of the Department of Labour will now co-ordinate all activity relating to safety and health in the workplace. The new Act has drawn together health and safety legislation and responsibilities from the Ministry of Transport, Accident Compensation and Rehabilitation and Insurance Corporation, Area Health Boards, Department of Health and Ministry of Commerce, to join those already administered by the Department of Labour.

With the change in government in 1990, the direction of health and safety policies changed significantly. To reflect the policies of the current government, the proposed hazard analysis standard has been changed from mandatory regulations into a code of practice. The proposed code will offer a means to compliance with the new Act, recognising that there is more than one route toward satisfactory safety management. In the new Act, there are a series of sections dealing specifically with hazard appraisal. For the first time, New Zealand safety legislation will require employers to identify the hazards within their workplaces and then to institute measures to eliminate, isolate or reduce those hazards and to minimise their potential effects. Thus, it will be a statutory requirement for all factories to carry out formal hazard evaluations of their facilities.

1.2 Nature and Scope of Project

With the widespread use of computers, use of safety assurance software is becoming an increasingly popular way of quickly analysing hazards at a given site. The aim of this project was to prepare safety assurance software for quantitative analysis, applicable to the New Zealand industrial scene. Other safety assurance software packages are currently available for use in New Zealand, but because of the cost, are generally only used in the larger installations. To be useful to the main proportion of New Zealand industry, any software produced had to be simple to use, inexpensive and appropriate to the scale and nature of the likely hazards. The software also had to be able to operate with a minimal amount of crude data. Because of the scale of New Zealand's industrial activity, data related to industrial safety are sparse. There is a need to assemble relevant New Zealand data, perhaps within a national database, rather than rely on existing data in the open literature and in commercial databases. These data relate to large scale industrial activities, often near large residential populations, and to management practices differing from those in New Zealand.

With relatively simple software, there was expected to be a trade off with a corresponding quality of analysis, Thus the second part of the project was to evaluate the software. Software produced had to be validated against an internationally used methods to at least show that the methodology used and application were within the limits of expectation. Through this comparison, the inherent limitations of the software were also to be evaluated.

2.0 SAFETY ASSESSMENT METHODS

2.1 Introduction

The terms 'risk' and 'hazard' are often confused, while the term 'risk' is used when dealing with hazardous events in industrial installations as well as the incidence of adverse events in financial and other matters.

In this thesis, a 'hazard' shall be defined as a situation, substance, phenomenon or activity that has an actual or potential ability to cause harm . Risk is generally considered to be the likelihood of an undesired event within a given period (Health and Safety Executive, 1989). It may be expressed either as a frequency (the number of specified events in a unit time) or as a probability (the probability of a specified event following a prior event), depending on the circumstances (International Labour Office, 1991). In it simplest form, risk is calculated by multiplying frequencies of failures (leading to hazardous events) by a numerical estimation of the consequences of that hazard.

The terms hazard analysis and risk assessment are used interchangeably in texts, and essentially they refer to the quantitative evaluation of hazards. In determining the safety of a particular site, the hazards are analysed so that the risk of a lack of safety can be assessed. In this thesis, hazard analysis is the preferred term. The risk on a site can change easily with a new shift of operational staff or a change in climate while the hazard potential remains constant.

Keey (1992) prefers the definition of risk as the probability of a specific hazard (becoming hazardous). The specified consequence arising, should that hazard occur, is termed 'outcome' and Keey defines 'hazardousness' as a function of 'risk' and 'outcome', as previously defined. This method moves away from the classical risk definitions and uses the term 'risk' as only a contributing factor to the term 'hazardousness'. This avoid the problem of calculating risk at high-hazard, low-risk installations such as nuclear power plants. For a loss of coolant accident, the classical risk function is a function of near zero frequency and near infinite consequence. This leads to a higher uncertainty of the risk result, and thus diminishes the value of that result for further analysis.

2.2 Qualitative Methods

There are two types of method of hazard analysis, qualitative and quantitative methods. The qualitative method adopts a structured, holistic approach to a systems analysis. An example of a qualitative assessment is a checklist. A checklist normally contains all of the elements of a good safety management system. Plant management may get a perspective of the magnitude of risk in an installation by checking the installation's safety management system against the elements on the checklist to rate their safety performance.

The use of checklists in qualitative risk assessment can be extended into the auditing of plant safety. This is one of the most commonly used methods of safety assurance. The plant is usually audited against a series of criteria deemed necessary for safe management. These criteria or fundamental elements of safety are usually set as points or questions to be asked of site management and employees. Audit procedures such as the International Safety Rating System (ISRS) have set up worldwide standards for safety management quality. Safety audit standards have also been embedded into corporate strategies. The only concern with audit procedures is that sometimes adherence to the letter of the audit requirement is seen as more important that adhering to the basic tenets of good safety management.

The Hazard and Operability study, also known as HAZOP is an open ended qualitative procedure for identifying complex failure scenarios that involve multiple independent events (Gressel and Gideon, 1991). The technique is applied in a group that seeks contribution from technical professions on and off site that have useful knowledge about the process to be analysed. This group may include mechanical, chemical and electrical engineers as well as chemists, and operational staff.

The plant is first split into small process units. The group involved in the analysis then considers the effects of a series of process deviations on the unit in question, usually working off a process and instrumentation diagram.. The group will recommend improvements to the unit, depending on the likelihood and consequences of those deviations. The HAZOP is one of the most powerful techniques used to identify potential hazards. It is used in many stages of a plant's operating life from its conception on the drawing board and through all its proposed modifications.

2.3 Quantitative Methods

Quantitative analysis is the method of assigning risk values to hazardous situations. It is generally termed quantitative risk assessment (QRA) and is also a widely used method. The numbers attributed to the 'risk' of a system are useful for comparisons with; other systems, the same system after a period of time or after modifications have taken place, and to defined risk acceptability criteria. Corran (1987) states that the quantitative assessment of process plants is extremely valuable because it enables the risks to be appreciated by those only peripherally interested in the technicalities. With a large proportion of boards of directors, etc. having minimal technical experience, this point is very important. Aside from the differences in definitions, the classical methodology of a quantitative method conforms generally to that shown in Figure 2.1. Note that a qualitative method plays a part in the analysis, with a holistic identification of the hazards which arise at a given site.

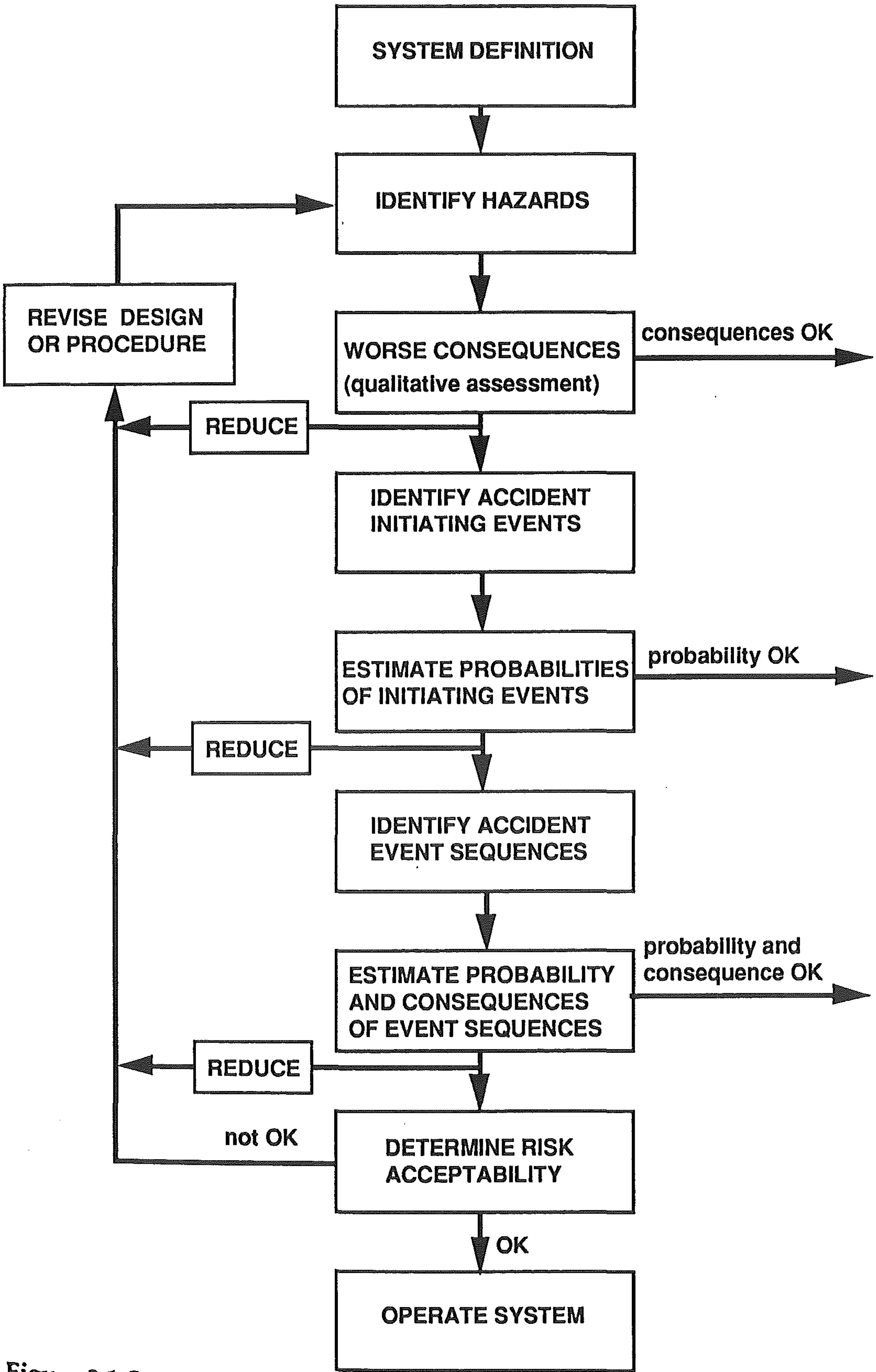


Figure 2.1 Steps In Quantitative Risk Assessment (Pickford and Corran, 1986)

While Figure 2.1 shows the classical methodology for a quantitative method, there are many techniques available to apply the methodology. These techniques are of varying levels of sophistication and are designed to achieve different ends.

A complex analysis of a plant will require the use of several different techniques. These techniques can be represented by task boxes in the methodology diagram in Figure 1.

Fault tree analysis (Hope 1984a) is a method that estimates the likelihood of a particular adverse outcome. This event is first placed at the top of the fault tree. The next step is to define all of the causative events that could have contributed to that top event. Once these events are defined (and the events contributing to those, etc.), probabilities and frequencies for the bottom events are set. Using Boolean operations, all higher event likelihoods are calculated, up to the likelihood of the initially defined top event. The sequence of events is simplifies to give a minimum cut set to produce the specified outcome.

This method is especially useful for tracking the relative impacts of contributing events to identify areas worthy of modification. The analysis can also be used in accident investigation (Barker 1990) to systematically identify possible events that have already caused a top event incident. The major limitation of fault tree analysis is that due to the number of combinations of possible lower level events it can be subject to error, as some pathways to failure can be easily overlooked.

Failure modes and effects analysis (or FEMA) uses a similar approach to fault tree analysis (Gressel and Gideon, 1991), except that the analysis starts with an individual component and then assesses the consequences of that component failing. The failure is essentially set as the bottom event in the analysis. The major advantage of this method is that all failure possibilities for that component are identified. Those with significant consequences can be flagged for further analysis. While the method is rigorous for that component, it does not evaluate the effects of two or more component failures.

The Monte Carlo Method (Hurst 1989) uses a similar modelling process as fault tree analysis, but takes into account the uncertainties involved in risk estimation. Instead of a fixed value estimated for likelihoods and other contributing factors, values are given in a range. Using random number generation to give values within the set ranges, a risk calculation is repeatedly executed (usually on a computer) to give a statistical distribution of the risk values. These data can be approximated to known statistical distributions, and ancillary statistical data such as variance can be used to evaluate the accuracy of risk values used.

While techniques such as FMEA and fault tree analysis estimate modes and likelihood of failure, other methods are necessary to estimate the consequences of these failures. A consequence is a physical manifestation of a hazardous situation. In the case of a propane vapour explosion, the consequence would be a blast wave or thermal radiation. The impact is the severity to which that consequence affects a target group. The target group may be persons, property or the environment. In the case of the propane explosion, the impact on persons may be numerous casualties with second or third degree burns.

Consequence analysis is generally an empirical assessment. Quantities and properties of hazardous substances are assessed, alongside physical factors such as ambient temperature, wind speed, etc. Some consequence models, such as toxic gas dispersion are estimations derived from physical properties of substances (Lees 1980), while many explosion models are derived from trials and case studies (Major Hazard Assessment Panel 1989, Technica 1985). Because of the complexity of the phenomena involved, good estimates need complex calculations which are time consuming and require a range of data. These data often difficult to obtain.

Using these techniques, hazards can be analysed to quantify the risks. Depending on the application of those results, the techniques can be used in a variety of ways. The Health and Safety Executive in the United Kingdom has developed a computer package called RISKAT (Hurst 1989) or RISK Assessment Tool. The basis of this evaluation is a dose criterion. Equivalent measures of harm are defined for the variety of different hazards on site. The notion of equivalent measures of harm follows several years experience by the Health and Safety Executive (Health and Safety Executive, 1989) of using a 'dangerous dose' criterion. The 'dangerous dose' has the potential to cause death, but will not necessarily do so. Equivalent measures of harm are the preferred criteria because of the difficulty in choosing doses with similar degrees of danger. Equivalent measures of harm have been derived with the aid of probit functions (Lees, 1980), which give a better appreciation of equivalent degrees of danger.

In its hazard evaluation of a site, RISKAT calculates the likelihood of exceeding these dose criteria. The application of RISKAT is different from most industrial applications which analyse a system to estimate the risk (or potential dose) already existing, and then compare it to some acceptability criteria to see if modifications to that system are necessary.

3.0 SIMPLIFIED RISK EVALUATION

3.1 Risk Ranking As A Valid Method For New Zealand

New Zealand is a relatively small country in terms of its land area and population, but it has a wealth of natural resources. The commercial exploitation of these resources means that the country has a considerable breadth of process industries which are likely to increase in importance. Under the requirements of the Resource Management Act 1991, with its thrust towards sustainability and zero environmental impacts, good management of site safety and loss prevention is playing a bigger part of retaining plant viability. The costs of down-time are increasing, as are the cost of plant insurance, accident compensation levies (Parliamentary Counsel Office, 1992a), the punitive measures for unsafe work practices (Parliamentary Counsel Office, 1992b) and environmental degradation (Parliamentary Counsel Office, 1991).

While some of New Zealand's larger process installations have multi-national backing and can provide a complex quantitative analysis of hazards on-site from their own resources, by far the majority can not. The size of the New Zealand economy makes it prohibitive. The methods use classical techniques of quantitative assessment, which are heavily dependant on large amounts of failure and other data. They also need expensive computational resources and expensive expertise.

In recent years, several methods of hazard analysis have been developed that are easy to apply, inexpensive to use, yet still provide useful results. These methods involve the rapid ranking of process hazards. In essence, these methods use simple assessments to assign semi-quantitative values to hazards within a defined system. These hazards can be ranked for that particular system. This ranking can be used for prioritisation of planned action

(Chidambariah 1991) and comparative analyses with other systems or the same systems over a period of time. Rapid ranking of hazards allows site management to perceive how risks are distributed across the compartments of that site. These types of methods allow resources to be allocated most effectively in the modification of systems to reduce hazards progressively.

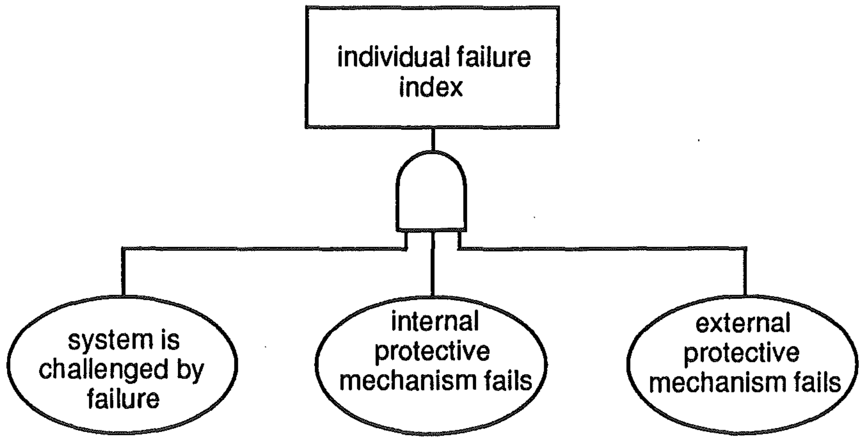
3.2 A Summary Of Techniques

Most rapid-ranking systems are based on the use of verbal descriptors to link hazards and their incidence with simple quantitative scores. An example of this is the criteria adopted in NFPA 704 " A Standard System For The Identification Of The Fire Hazards Of Materials" (NFPA 1990). This standard sets criteria for assessing the relative flammability, reactivity and health hazard of materials. Using descriptive criteria, materials are given scores between 0 (no hazard) and 4 (maximum hazard). Using these scores, a quick perception can be made of the relative hazardousness of several substances.

The Dow Fire and Explosion Index (Dow Chemical Corp 1987) takes this type of ranking one step further, dividing a site into compartments with potentials for causing fires and explosions. The index uses the NFPA 704 material scoring method for substances within those compartments, and has inputs referring to process conditions, site topography and the use of hazard mitigation devices, to calculate an effective exposure radius around the selected hazardous locations on site.

In his work, Lapp (1990) has devised a system that uses a variant of fault tree analysis to calculate risk scores. The Major Risk Index System initially sets up a fault tree for all failures occurring within a defined system. For each of these failures, an individual failure index is calculated. This calculation assumes that for a failure to become a hazardous event, three things must all happen. The system must first be challenged (by the failure), then both the internal and external protective mechanisms must fail. Thus the individual index is seen as being at the top of a fault tree with an AND gate. Estimations for the frequency of system challenging events are multiplied by the probabilities of both each protective failure (see Figure 3.2.1).

Figure 3.2.1 Individual Index Calculation (Lapp 1990)



These individual failure indices are treated as being independent of each other. The total site index is calculated using the fault-tree method through an OR gate. Thus the site index is the sum of the individual indices (see Figure 3.2.2).

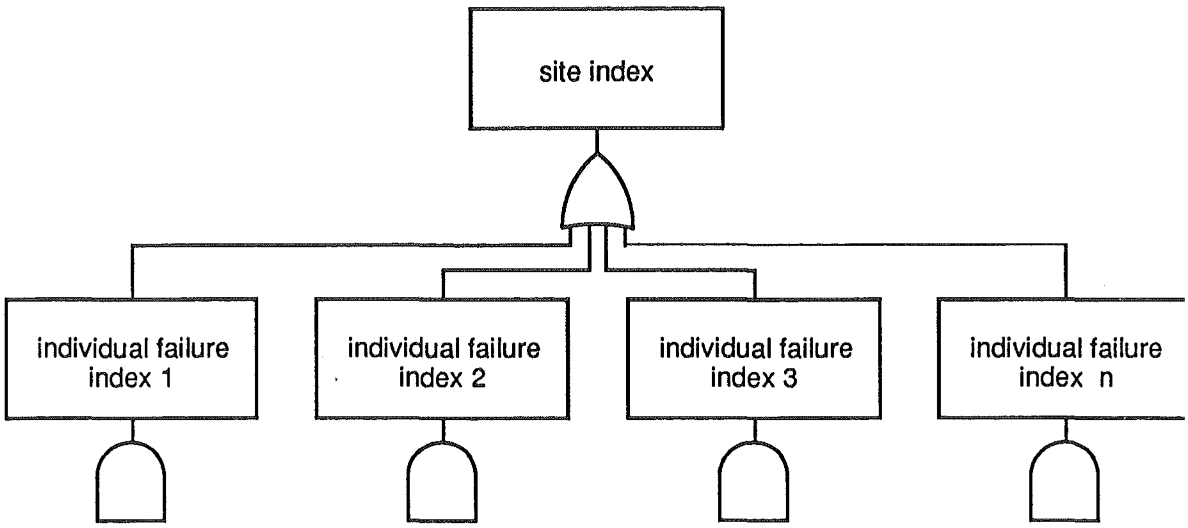


Figure 3.2.2 Site Index Calculation (Lapp 1990)

3.3 Tweeddale's and Keey's Methodologies

To fit a specific New Zealand situation at Rosebank Peninsula, Wood and Tweeddale (1989, GCNZ 1989) developed a methodology for determining a set of risk indices. The method is based on an earlier simplified analysis developed by ICI plc (Keey 1987). In this methodology, they assign semi-quantitative scores to an index equation by equating hazardous phenomena on a site to a score using a form of verbal descriptor.

This equation reads

$$(R) = (F) \times (S) \times (P)$$

Where (R) the risk index is calculated by multiplying (F), the designating frequency of the hazard causing event by (S), the severity of consequences and (P) the likelihood of the incident not being mitigated. The severity of consequences are measured against three impact groups. These are persons, property and the environment. In this method, hazard indices are calculated for each of these impact groups. The criteria for assigning these values are given in Tables 3.3.1-3.3.5 below.

Table 3.3.1. Frequency Scale for Initiation of Incidents (F) (Wood and Tweeddale 1989)

DESCRIPTION	FREQUENCY PER MILLION PER YEAR
Very Frequent	500000
Likely	100000
Possible	10000
Unlikely	1000
Very Unlikely	100
Barely Credible	10

Table 3.3.2. Scale of Severity Describing Effect on People (S) (Wood and Tweeddale 1989

EFFECT	SEVERITY SCORE
Several dead	Number of dead
1 dead	1.0
Significant chance of a fatality	.8
Small chance of a fatality or severe nuisance to many people	.3
Severe nuisance to a few people or a nuisance to many people	.1
Nuisance to a few people	.01
Minor nuisance to few people	.001

Table 3.3.3. Scale of Severity of Effect on Property (S)
(GCNZ Consultants, 1989)

Effect	Severity Score
Several houses destroyed	Number of Houses
Whole of adjacent factory destroyed	3-10
One house destroyed	1
Originating factory destroyed, or part of adjacent factory destroyed or major part of residential house destroyed	0.3
Part of originating factory destroyed, or minor damage to adjacent factory or minor part of residential house destroyed	0.03-0.1
Minor damage to originating factory	0.001-0.01

Table 3.3.4. Scale of Severity of Effect on Environment (S)
(GCNZ Consultants, 1989)

Effect	Severity Unit
Intense local and long term (>12 months) effect, or high potential for widespread impact	2-10
Intense local but short term effect (<12 months) or moderate potential for widespread impact	1.0
Moderate local and long term (>12 months) effect, or low potential for widespread impact	0.3
Moderate local but short term (<12 months) effect	0.1
Minor local short term effect (<12 months)	0.01
Minor local short term effect (<3 months)	0.001-0.003

Table 3.3.5. Scale for Probability of Failure of Protective or Emergency Response (P)
(Wood and Tweeddale 1989)

DESCRIPTION	PROBABILITY
Negligible chance of effective response	1.0
Low chance of effective response	.7
Fair chance of effective response	.3
Good chance of effective response	.1
Very good chance of effective response	.03
Exceptional chance of effective response	.01

The frequency of the hazard causing event is measured per million years, while the severity scale has a top scale reading of the number dead in a multiple fatality accident, reducing in severity to fractions of one fatality. This gives an index unit of expected mortalities per million years for impact to persons. Severity, in terms of impact to property, has the meaning of expected building damage per million years and that to the environment is the number of incidents which are likely to have a widespread effect.

In a refinement of the work by Wood and Tweeddale, Keey (1991a) pointed out that in measuring the impact on people, the use of multiple and fractional fatalities on the same consequence scale was inappropriate. The social cost of a fatality and its lack of 'reversibility' meant that a fractional fatality representing illness or injury resulted in a mix of units on this scale. In his refined methodology, Keey chose as a consequence scale, a count of those persons that had been seriously affected by the hazard in question. Whether they are affected by death, illness, injury or psychologically was left implicit. With this scale, a wider raft of effects can be considered. While no specific criteria for 'seriously affected' is set, it can be defined as per the requirements of the assessment. This approach is consistent with the use of the 'dangerous dose' by the United Kingdom Health and Safety Executive in evaluating hazardous sites (Health and Safety Executive, 1989).

Keey also suggested that the reference time interval for the designated frequency be reduced from one million years to one hundred. This would give a better perspective to analysts and those using the information without the benefit of a technical background, by working on the basis of a human lifetime. The revised frequency choices are shown in Table 3.3.6. With respect to the severity of consequences to the environment, Keey suggested that the scale be aligned with the impacts on the number of target organisms.

Table 3.3.6. Frequency Scale For Initiation Of Accidents (Keey 1991a)

Descriptor	Numerical Value (*f* per 100 years)
Very Often	1000 (once per month)
Often	100 (once per year)
Likely	10
Possible	1 (once per lifetime)
Unlikely	0.1
Very Unlikely	0.01
Barely Credible	0.001

Keey also changed the scale for mitigation descriptors from the scale used by Wood and Tweeddale, which was biased toward success to a symmetrical table, revolving around the descriptor of a 'fair' mitigation response. This table is shown in Table 3.3.7.

Table 3.3.7. Scale Of Likelihood Of Failure To Contain An Incident (Keey 1991a)

Descriptor	Probability of Success	Probability of Failure
Negligible chance of an effective response	0	1
Low chance of an effective response	.2	.8
Fair chance of an effective response	.5	.5
Good chance of an effective response	.8	.2
Negligible chance that mishap will escalate	1	0

Keey's equation is defined as the product;

$$(\text{incident index}) = (\text{frequency}) \times (\text{numbers affected})$$
$$\times\ (\text{chance of an ineffective response})$$

It was decided to use the Keey methodology as a base methodology for this project. This was because it offered a simple form of quantitative assessment to New Zealand industry, was well structured, relatively easily modifiable to software and worthy of further application.

4.0 PROJECT METHODOLOGY

4.1 Features of proposed methodology

The methodology to be used in this project was changed slightly from Keey to more effectively accommodate the aims of this project and its transfer into software.

The methodology will be based on the equation;

$$(\text{hazard index}) = (\text{frequency}) \times (\text{numbers affected}) \times (\text{chance of an ineffective response})$$

The index will be called a hazard index instead of an incident index because it is felt that the index is more aligned to the hazards within the plant, with an incident effectively being the conduit between a hazard and a hazardous situation. The term 'chance of ineffective response' is the probability that mitigation devices installed will fail, thus the terms can be used interchangeably. The equation closely fits the terminology used by Keey (1992). Based on his definitions, risk is the probability of a hazard occurring. In the terms of the equation above, this will be the frequency of failure multiplied by the chance of an ineffective emergency response. Keey then terms hazardousness as a function of risk and outcome. This function at its simplest is risk multiplied by outcome. In the above equation the outcome with respect to people will be the numbers affected. Thus the index will be an indication of the hazardousness of the site.

The methodology within the software will concentrate on the effects the site's hazards have on people. This will streamline the approach and represent the interest of this project's funding agencies. The application of the methodology to software forced no changes to the methodology, but it did give an opportunity to refine the methodology, using the benefits of computer execution.

Of the three contributing factors to the hazard indices, the estimation of persons seriously affected was identified as being the most uncertain. It was decided to actively place personnel on a graphic image of the defined site and then run consequence models for each hazard to estimate the magnitude of area of the site that is significantly affected by those hazards. Personnel placed within an area 'affected' by that hazard would be considered 'seriously affected'. It was thought worthwhile to adopt both discrete and uniform personnel placement because of the different types of work they encompass. Administrative personnel on site will spend their whole working day in one discrete location, while process workers could be called upon to work anywhere on site or within a particular zone . In the case of sites with shiftwork, 24 hours per day, seven days per week, the discrete and uniform positioning of staff will reflect that those worker positions will be exposed to plant hazards four times longer than day staff.

Numbers of people affected were estimated by assuming the effect distances to be radial around the hazard epicentre in question and adding up the people within the confines of that hazard's effect radius. It is recognised that the consequences of a hazard are rarely equivalent in all directions, due to the type of hazard, wind flow or site topography. The approximation of having circular effect zones was deemed valid because the term 'seriously affected' was seen as a range of impacts including evacuations as well as injuries, illnesses, psychological disorders and fatalities. This term would thus certainly envelop the impacts experienced on both the downwind and upwind plant sections during a fire, toxic release or explosion, etc.

There were two options available for the source of the consequence data. The data could either be derived from models programmed into the new software or from a commercial consequence package. Considering that the consequence models used were going to be very similar, it was decided to avoid duplication and calculate consequence data off-line with a commercial package. Consequence data would be added at appropriate points during program execution in the first instance.

As mentioned, to use the consequence routines, a graphic image of the site needed to be generated. This meant that the analysis could be centred on the site topography, with respect to the siting of the hazardous compartments and personnel. This approach would also give the user an appreciation of the magnitude of the hazards involved. The methodology described is shown in Figure 4.2

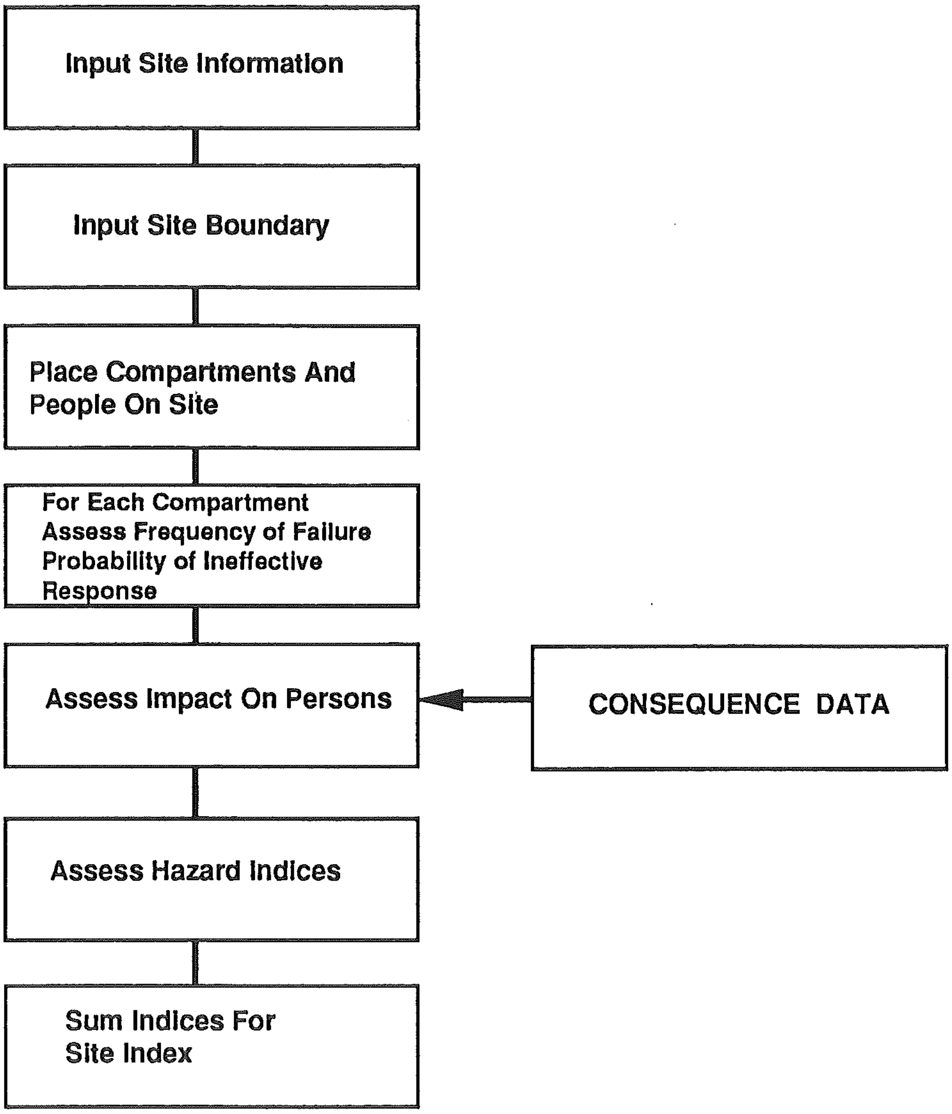


Figure 4.2 Project Methodology

5.0 PROJECT SOFTWARE

5.1 Reasons for implementation into software

With a basic methodology defined, the next step was to encode that methodology into software. Some quantitative methodologies are put into software because of their complexity and the need to perform repetitive calculations to develop risk profiles, e.g SAFETI (Pitblado and Nalpanis, 1989). A computer is far faster and more accurate in complex or time consuming calculations, iterations and graphical representation than one or more human analysts.

These were not the prime reasons to convert this methodology into software. Instead, it was considered that transferring the methodology into software would set a formalised routine for the analyst to follow. This would hopefully lead to better reproducibility of results for the same or other analysts, and provide a consistent basis for regulatory assessment of sites.

Once the basic methodology was encoded, other routines were added to further help the analyst make decisions with reference to the descriptive criteria. This was intended to reduce the dependence on the expertise and experience of the analyst.

5.2 Choice of Programming Software

At the beginning of the project, no specification was set for the programming software to be used. It was realised that the implementation of the methodology into code was not going to be a particularly complex process as the methodology only included data entry, simple graphics, data manipulation and output. The basis of the project was more of an exercise in method evaluation than in software design.

The main requirements for the programming software was for its ease in use and implementation. Considering that any end product was to be made easy to utilise by smaller New Zealand industries, it was also important that it could run on desktop microcomputers of modest performance.

The programming software chosen was Microsoft Quick Basic. For the convenience the computer used for programming was an Apple Macintosh SE 30, thus the Quick Basic used was specifically for the Macintosh range of computers. It is important to note that there is also a version of Microsoft Quick Basic available for the MS. DOS machines, and that the code is almost identical. While the Macintosh SE 30 is a powerful machine with a maths co-processor, the software will run on any Apple Macintosh and any IBM compatible computer with a processor at least as powerful as the XT type. The minimum RAM memory requirement for program execution is 512 kilobytes.

The other advantage of Microsoft Quick Basic is that while being relatively simple to encode, it retains a logical structure similar to the more complex programming languages available. Unlike the cruder Basic forms (Basica, GW Basic) Quickbasic needs no line numbers and can be compiled into an executable file in the international standard 68020 form. Compiling is a process where the code is transcribed from a statement format into a machine code. This is advantageous for two reasons. First, the machine code is faster for the computer to read, so the program becomes faster to run. Secondly, the transcribed version does not need the programming software to be resident in the computer's memory for the programmed software to run. It will run as a stand alone program, unlike the uncompiled version. This capability also lends itself to being useful for smaller industries, by circulation of the programmed software alone.

5.3 The Software

This software is run as a series of subroutines, called from a main program. This part of the chapter will discuss the way that these routines are called and how they work to calculate the hazard index of a site. The names of subroutines will be printed in upper case. To get a better impression of the way these subroutines are called, refer to Figures 5.3.1a and 5.3.1b for the flow chart of the project software. A listing of the project software, Hazrank can be found in Appendix 2, along with a list of variable explanation in Appendix 3 and quick reference subroutine explanations in Appendix 4

The program starts by entering the START subroutine. Here, variables such as pi are initialised, arrays are dimensioned and data statements are read into the arrays. Data statements are used to load regularly used words or phrases into arrays for the use in the descriptor tables. The title screen is shown and then the user is asked the name of the site. Later in the program, an output file will be opened. The name of the file will be the same as the site name for easy referral to data. The date and time the file was created is saved with the file, when it is opened, this is useful for chronological reference. To continue beyond the START routine, the user must press the space bar. The space bar must be pushed at the end of each subroutine because in the compiled form of the software the repeat function in the key starts after a short time. Too much pressure on the return key at the end of a routine can result in a zero value being entered into the first entry value in the next routine.

The next routine is ENTERSITE. In this routine, the site boundary co-ordinates are entered. To ease the placement of these co-ordinates, a 10x10 grid is printed onto the screen, with the numbers 0 to 10 printed along each side. For each co-ordinate, a number between 0 and 10 is entered and then changed into pixel co-ordinates. The numbers that identify the grid lines are generated in another subroutine called NUMPRINT. These numbers are only 6 pixels high by 3 wide and can be placed accurately on the screen. This subroutine was necessary because the limited software graphics capability of the Quick Basic software meant it was only able to print numbers in a text mode at full size. Numbers printed in this mode were three times as large and were only able to be placed on the 60 character wide, 18 character high screen matrix. This made the final output far too cluttered and difficult to place the numbers accurately. NUMPRINT works by entering the value of the number, and its pixel co-ordinates. These values go into the routine, where a pixel representation of that number is printed at those co-ordinates. By inputting numbers on the pixel co-ordinates, the software was able to take advantage of more accurate placement in the 495 pixel wide by 295 pixel high graphics matrix.

When the user enters boundary data, they enter any real number between 0 and 10. At each co-ordinate point, a 2 pixel by 2 pixel black square is plotted. After each co-ordinate entry, lines are drawn to connect the all co-ordinate points entered so far. The software assumes that any boundary will be a closed shape, so after the second to last entry has been specified, a boundary line will be automatically drawn back to the first co-ordinate point.

No site boundary co-ordinates are accepted if they are not real numbers between 0 and 10. Each entry is validated, and the user asked to repeat the co-ordinate entry for that point, if either co-ordinate value is invalid.

Once all of the site co-ordinates are entered, the site is printed on the screen without the grid, so that the user can get a better perspective of the shape. The user is then given the opportunity to change any site boundary co-ordinates. The co-ordinates are printed in tabular form on the screen in text mode. If the user wishes to make a change, the incorrect boundary point is identified and the user is then able to enter correct co-ordinates. This process is repeated until the user indicates that no change is necessary.

Next, the user is asked to enter the bearing and a metric dimension for a horizontal grid unit. This allows a scale to be calculated. The bearing is printed in the final output file. An arrow is drawn with a graphic "N" to show the direction of North. In this version this adaptation is purely for cosmetic reasons. The site area is then approximated by calculating the size of the square defined by the extreme site co-ordinates at the left, right, top and bottom of the screen.

The next routine called is INPUTPEOPLE. Its first request from the user is to enter the number of personnel on site. The user is then asked the number of those personnel that can be discretely placed on site. The remaining personnel are assumed to be placed uniformly on site, with a uniform personnel density calculated by dividing the number of uniformly distributed people by the approximate site area calculated earlier. In a continuous plant, site locations will be occupied 24 hours per day and seven days per week or 168 hours per week. Process day workers and administrative staff will only be in their workplaces for approximately 40 hours per week. Clearly, in the case of continuous plant, a catastrophic event has approximately a quarter of the likelihood of affecting the day workers. To take this into account for the analysis, when the personnel are entered, the user is asked if the job is to be filled 24 hours per day. If not, the number of people affected in that bunch is divided by four. The uniform distribution is likewise altered in the calculation of uniform personnel density. The community risk for day working is a quarter of that for continuous 24 hour shift working, although the risk for an individual worker is the same for an equal contact time.

The placement of discrete personnel on site is done on the 10x10 grid, with numbers generated from the NUMPRINT subroutine used to indicate clumps of people. The printing of these clumps of people is done through the routine DRAWPERS, and is intended to convey useful information on to the screen. Whether the clumps of people are on the site for 24 hours or not is not shown on the screen. The information is kept in a parallel array for reference in later calculations.

In ENTERCOMP, the locations of potentially hazardous compartments are placed on the site. Once again, the placement is done through the 10x10 grid. As co-ordinates are entered, a 3 pixel by 3 pixel black square is plotted at the co-ordinates, with an identifying number underneath. The number is generated through NUMPRINT and a hash mark is printed alongside. As with ENTERSITE, compartment co-ordinates are validated, so that the only co-ordinates accepted are real numbers between 0 and 10. Once the compartment co-ordinates are entered, the user is asked the name and hazardous effect radius for each. The effect radii will be derived from the WHAZAN II consequence analysis.

ENTFREQ is the next routine. In this routine, the user is asked to choose the failure frequency and probability of mitigation failure for each compartment. The choices will be made from descriptor tables that are printed on the screen. These tables are similar to the descriptor tables mentioned in the Keey methodology, except that they have identification codes printed alongside frequencies and probabilities to help the user make their selection. Values for these choices are stored in arrays aligned to the compartment number.

The last main routine in the software is FINAL. FINAL prepares and presents the output data. It first calls a subroutine called EVALUATE to calculate the numbers of people affected by each hazardous compartment.. For each compartment, the area within the effect radii is multiplied by the uniform personnel density. Each discrete clump of personnel is then tested to see if it comes within the effect radii using the theorem of pythagorus (calculating the hypotenuse of a triangle, knowing the relative difference of the x and y co-ordinates between the compartment and the personnel site in question). The sum of these values give a total for people affected by that compartment. It is recognised that incorrect assumptions are taken when uniform numbers of people are calculated to be seriously affected by a compartment when its effect radii goes beyond the site boundary. Clearly, a hazard that can manifest itself outside the boundary should not be ignored, but multiplying the area it influences by the on site personnel density is inappropriate. It has been retained in its current form and regarded as inaccurate. No solution has yet been decided upon as any more manipulation of these data could well involve more incorrect assumptions.

The FINAL routine then calls the subroutine CALCINDICES, where the output data file is opened. The software prints the site data to both the output file and screen. These data are; the site name and personnel data and for each compartment, its name and identification number, failure frequency, mitigation probability, number of persons affected, the compartment hazard index calculated and the total site index, summed from the individual compartment hazard indices. The Apple Macintosh clipboard is then opened for a graphic insertion. The software prints to the screen and clipboard a graphic image of the site boundary, compartment locations with effect radii, a scale in a gradation of ten and twenty metres, an arrow showing the direction of north and the situation of discrete personnel numbers.

The site output file can be opened through any word processing package. Once it is opened, the site graphic can be pasted on to the bottom of the text and the file can be saved as a whole.

The interrelationship of these routines are more clearly shown in the subroutine diagram in Appendix 6.

Figure 5.3.1a Flow chart of Encoded Method

Bracket bars at the side of the chart refer to the relevant subroutine.

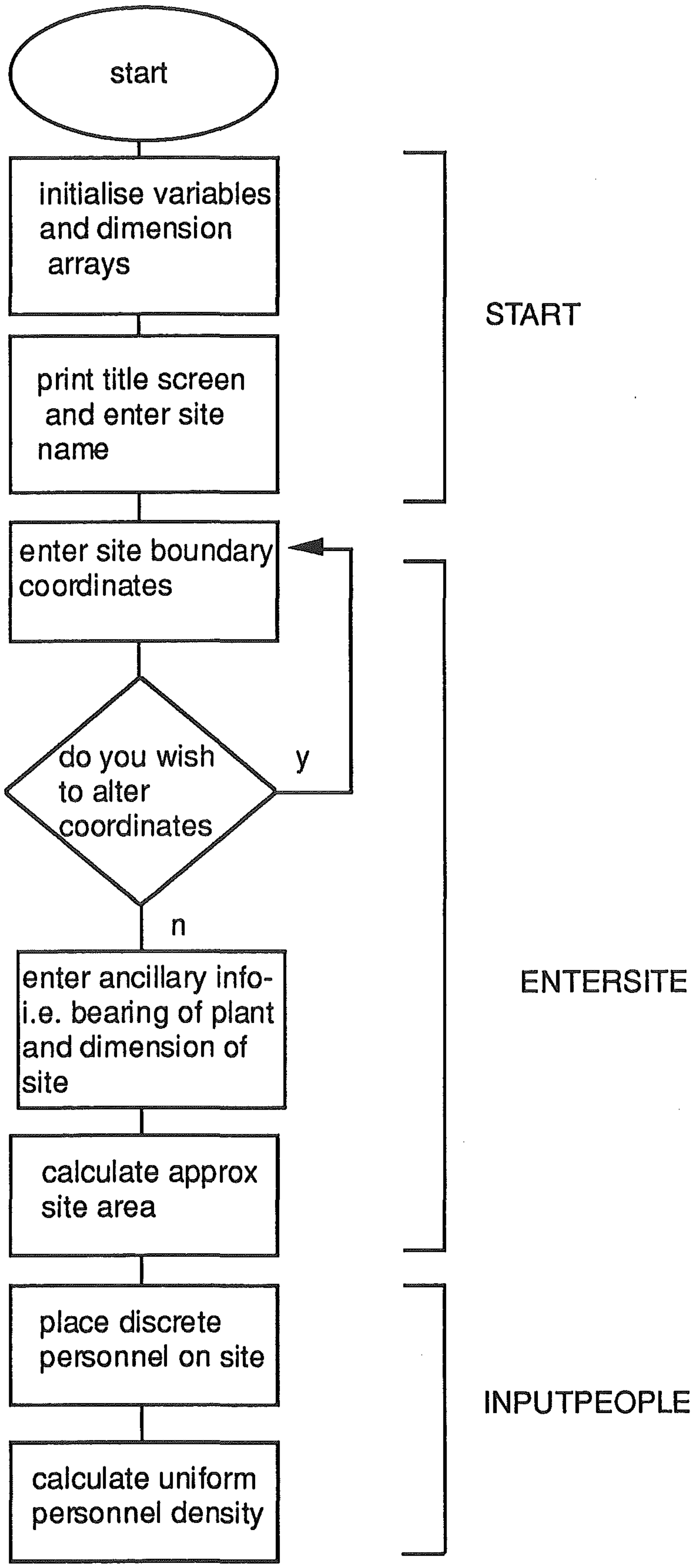
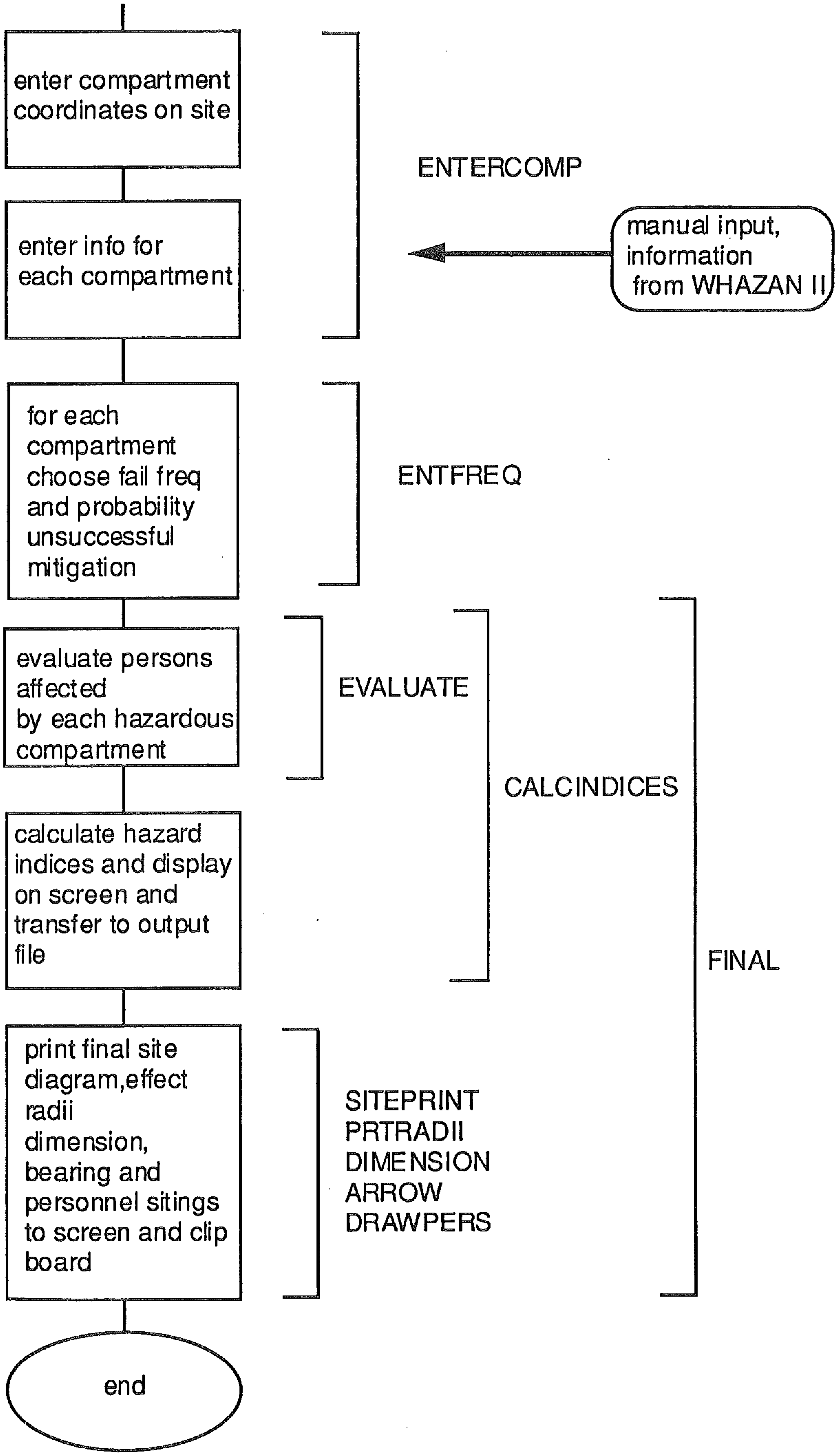


Figure 5.3.1b Flow chart of Encoded Method



5.4 Whazan II

The software chosen for the consequence analysis was Whazan II (DNV Technica 1992). Whazan II is a MS. DOS compatible consequence analysis software package with a chemicals database that estimates the consequences of a variety of process hazards. The software encompasses 17 consequence models and the physical properties of 20 hazardous substances. The hazardous substance database is expandable and modifiable.

The user first chooses a model and a hazardous substance, then inputs relevant site data. The type of site specific data generally requested is the ambient temperature, meteorological conditions and the nature of the pressure and temperature of the hazardous substance. The model then calculates the consequence and offers both hard and soft copy results. These results are usually in both graphical and tabular form. The user can choose another model for analysis at this point or vary the results of the previous analysis by inputting different conditions or another hazardous substance.

In an earlier version of the software, linked consequence models existed. A linked consequence model will run several consequence models sequentially, using the results of one model as input data for another. For example, an orifice flow model could give flow data that could be used in a jet fire or toxic gas release model. In Whazan II, the user has to develop such linkages from individual consequence models.

5.5 Cases not covered by Whazan II

It is important to note that the Whazan II software does not produce consequence data for all situations. One specialised type of hazardous event is a dust explosion. While dust and gas explosions share criteria like lower and upper explosive limits, empirical prediction of dust explosions is based on K_{St} values, volume of explosion containment and dust fineness (Schofield 1985). As dust explosion mechanisms are well known, consequence data for explosions can be estimated accurately. Coverage of dust explosions is especially important in a country like New Zealand. The country has several of its major industries involved in processing or producing fine organic or metallic powders and dusts, e.g. milk powder or flour production.

The dust explosion scenario starts with a primary explosion. This occurs when an ignition source ignites a cloud of dust (usually smaller than 250μm) in the presence of oxygen. If the explosion is within the confines of a vessel the over pressure can exceed eight bar (800kPa). As few vessels are able to withstand this amount of pressure, the containing vessel will normally rupture. Devices such as explosion venting or suppression will significantly mitigate these effects, but are not always utilised. In this type of explosion, people will be seriously affected within a radius of 20-30m. Of those affected, impact will be usually severe.

If the explosion takes place in a room, or the flame front escapes the vessel into the wider environment, a secondary type explosion can take place. In sites where there is processing or production of combustible dusts, excess dust can accumulate throughout the building. A secondary explosion occurs when the primary explosion blast or shock wave excites this accumulated dust. Upon ignition this cloud explodes, usually transmitting the flame and pressure wave throughout the building. These explosions are much more hazardous as they occur in the workers environment and their effects are almost impossible to mitigate. The area of where people will be seriously affected will be the entire containing building and probably another five or ten metres around its border to deal with the explosion's effects on the building, e.g. missiles, broken glass.

5.6 Use of consequence data

When considering the consequences of the hazards within the site compartments, it was important to estimate the magnitude of the effect the hazards would have on their surroundings. Many hazardous situations, such as electrocution, mechanical impact or corrosive chemicals have only localised effects. Their effect distances are usually less than 5m. The three main types of hazardous situation that have long range effects are fires, toxic releases and explosions. These effect distances are functions of the quantities of hazardous substances involved, their physical and chemical properties and site data such as wind speed and ambient temperature. Whazan II (DNV Technica 1992) was used to give estimates of these long range effects.

Whazan II is a consequence package. Inputs into the consequence models are data such as quantities of hazardous substances, and site conditions. The models use these data along with the physical and chemical data from its built in chemical data base to estimate the magnitudes of the physical manifestations of those hazards. The remaining task is to link these consequences to the impacts they will have on the persons within the site.

Considering the three types of long range hazards, it is important to set dose criteria for being seriously affected. Whazan II gives consequence information by relating changes in the magnitude of a particular hazard's physical manifestation with respect to distance. By defining the seriously affected dose criteria for each hazard, it is possible to estimate the radius from that hazard where serious effects will occur.

In the case of fires, the primary physical manifestation of the hazard is thermal radiation. A dose of 4.7 kW/m^2 was chosen for this criteria (see Appendix 1). This dose corresponds to second-degree burns occurring within 30 seconds. This was seen as the tier of effect where the effect was serious. The effects for the tier below (2.1 kW/m^2) were akin to bad sunburn (which is probably one of the most voluntarily exposed hazards these days).

The effects of a fire may be twofold. There will be thermal radiation (using the dose criteria mentioned previously) and there will be a blast over-pressure, i.e. the case of fires that result in detonations as a result of partial confinement. A blast over pressure of two psi (14 kPa) was chosen. From consequence tables (see Appendix 1), this pressure will cause a building to be to be badly cracked and uninhabitable. This criteria was selected because it fell between criteria giving a low chance of injury and a moderate chance of fatality. The severity of impact was seen as commensurate with that of thermal radiation. As well as people being caught in the blast, it was considered that the blast over-pressure would also contribute to people being affected psychologically, by injuries from building failures and from airborne missiles.

In the case of the toxic effects of hazardous substances, suitable criteria are already set. The Department of Labour regularly publish a book called "Workplace Exposure Standards and Biological Exposure Indices for New Zealand" (Department of Labour 1992). Based of the threshold limit values set overseas, this book sets the workplace exposure standards (WES) for a wide variety of hazardous substances. The WES is a recommended maximum exposure with a particular substance. Three type of levels are offered within the book. A time-weighted average (TWA) gives the maximum level of exposure that a person can tolerate in an eight hour day without effect. The short-term exposure limit (STEL) gives a maximum level that a person can be exposed to for a short time without serious effect. This exposure is allowed for four intervals of 15 minutes per day. The WES-Ceiling gives the level of exposure to any person that cannot be exceeded, even for an instant.

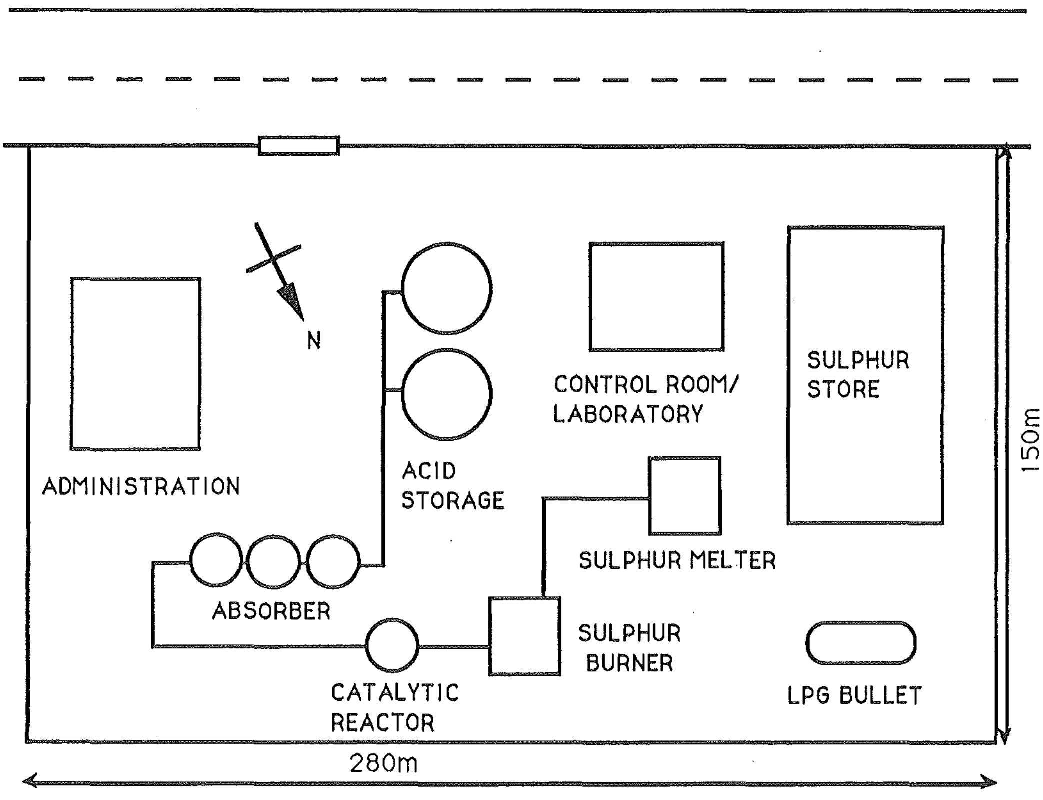
The STEL gives the most appropriate level for the exposure during an emergency as the TWA level would be reasonably commonplace on site. Where in the booklet, a STEL level is not available, a Ceiling or TWA level will still give a benchmark.

6.0 PROJECT OUTPUTS AND DISCUSSION

6.1 Test Case

To display how the software performs, the following site (see Figure 6.1.1) was designed as a test case. The site is a sulphuric acid plant.

Figure 6.1.1 Test Site



On the site there are four main regions of high potential hazard. These will be the four hazardous compartments used in the analysis.

1 - The sulphur melter. Sulphur is melted by steam from the boiler house. Due to variable product sources, hydrogen sulphide is sometimes liberated when the sulphur is being melted. There is exhaust ventilation, but condensing sulphur vapour can block the exhaust duct. Tests have shown that when this happens,

approximately one kilogram of hydrogen sulphide is released before an alarm sounds and other ventilation can be applied. Hydrogen sulphide has a WES (STEL) of 15ppm (Department of Labour 1992).

From the Whazan II consequence analysis of this situation (ref Appendix 11), the radius of fatality probability is approximately 50m. This distance was decided after using the Dense Cloud Dispersion model (H_2S has a relative density to air of 1.1895 (Perry and Chilton, 1983)). The consequence analysis gave a fatality probability of zero at distances above 20m, but the ground level concentration remained at 0.05 - 0.1 % (500-1000ppm) until over 50m. This distance was arbitrarily chosen because of the difficulty in interpreting the graph after 50m.

The simultaneous failure of the extraction system and melting of hydrogen sulphide tainted sulphur occurs about once in ten years, and the likelihood of effectively mitigating the effects of the failure can only be termed as 'fair'. Due to the small quantities of hydrogen sulphide evolved, the explosive hazard is considered negligible.

2 - The sulphur burner. Sulphur dioxide is produced from the oxidation of sulphur in the sulphur burner. Corrosive action of the sulphur dioxide has been known to cause the flange at the exit of the vessel to fail. This releases approximately 1 kilogram per second into the atmosphere. It takes two minutes for the alarms to detect the sulphur dioxide and for shift workers to fit a strap to block the leak. Sulphur dioxide has a WES (STEL) of 5ppm (Department of Labour 1992).

From the Whazan II consequence analysis of this situation (ref Appendix 11), the radius of fatality probability is approximately 80m. This distance was decided after using the Dense Cloud Dispersion model (SO_2 has a relative density to air of 1.434 (Perry and Chilton, 1983)). The consequence analysis did not give a fatality probability of zero until 50m distance was exceeded, but the ground level concentration ramps down to approximately 0.1% (1000ppm) until approximately 80m, where ground level concentration diminished to a level near zero (due to the resolution of the output graphs, fine interpretation is difficult).

From national statistics, the frequency of flange failure is estimated to be approximately 0.001 per year (or one failure per 1000 years) and the likelihood of effectively mitigating the effects of the failure can be termed as 'fair'.

3 - The LPG bullet on site has a capacity of 10 tonne. From the Whazan II analysis of this situation (ref Appendix 11), the radius of serious effect is approximately 180m. This distance is derived from matching the vulnerability criteria set in chapter 5.5 to the data gained from running both the Fireball/Bleve and the Vapour Cloud Explosion consequence models for propane and choosing the worst case. In the bleve calculation one sixth of the bullet's capacity is used in the calculation because a bleve only occurs when the vessel is half full and usually involves about a third of the remaining liquid (Keey, 1991b). Data from both models gave approximately equal distances.

From national statistics, the frequency of failure is estimated to be 0.0001 per year (or once in every ten thousand years) and the likelihood of effectively mitigating the effects of the failure can be termed as 'good'.

4 - The sulphuric acid storage tanks have a 70 tonne capacity and are situated in a wide bund that surrounds the tanks at a 20m radius.

The operators responsible for pumping out acid to tank wagons and circulating acid between the tanks, regularly allow the tanks to overflow and spill into the bund. From a qualitative analysis of this situation, the radius of serious effect is estimated at the bunded radius of 20m. The radius of effect should be no larger because the acid is concentrated and the bund has internal pumps for acid removal. People will be seriously affected within the bund because when the tanks leak, they leak very quickly and any contact with the acid will be serious. The bund area is also used as a thoroughfare from one side of the plant to the other. From recent site history, a pumping failure is estimated to occur about once a year. The likelihood of effectively mitigating the effects of the failure can be termed as 'good'.

The hazards from the catalytic reactor and sulphur store were not considered in this analysis. Plant management are currently negotiating contracts to significantly modify safety equipment in both units, so an analysis of them now would be misleading.

Personnel - There are 25 people on site, with 14 working in administration during the day, two shift workers on the control room and two day workers who pump out acid to tank wagons. There are two more day workers and five shift workers that work in all places around the site.

6.2 Analysis of results

The results from the analysis of the test site in example 1 give a site index of 18.44 (see Appendix 5 for complete output data from software and Figure 6.2.1 for summary of indices).

Figure 6.2.1 example 1 summary

sulphur melter index = 5.05

sulphur burner index = 0.13

LPG bullet index = 0.031

acid storage index = 13.23

site index = 18.44

The site index of 18.44 means that approximately 18 person on this site would be seriously affected by the four hazards specified over the 100 year reference period. The individual contributions of these effects show that over 99% of the people will be affected by the hydrogen sulphide emissions from the sulphur melter or the corrosive actions of concentrated sulphuric acid leaking from the bulk storage tanks. A further 0.7% will be affected by sulphur dioxide emissions and 0.2% affected by a leak from the LPG bullet.

The basis for the range in the effects of these hazards can be best seen in the relative analysis of the 'risk' terms, or the likelihood that a failure will become a hazardous situation. This value is the product of frequency of failure and the chance of an ineffective response. The values are as follows; sulphur melter 5, sulphur burner 0.05, LPG bullet 0.002 and acid storage 20. The two groups of results are over two orders of magnitude apart. This shows one of the most useful elements in a rapid ranking procedure, that high consequence, low frequency situations do not totally dominate the results in a hazard appraisal of a site. Due to lay perception of the risks involved and the emotive issues regarding multiple casualty events, the risks from bleves and vapour cloud explosions do tend to be overstated. The greatest error in this analysis would be in the estimation of the numbers of persons affected by the LPG bullet, because the area within its radius of effect is 75% off the site. This would indicate that the 0.2% contribution of site hazardousness from the LPG bullet is elevated.

This example shows that the likelihood of a hazardous situation plays the major role in the final index value, as it does in the ranking of hazards. According to this analysis, failures at the acid storage tanks are the most hazardous events on site. Within the broad umbrella term of 'seriously affected', corrosive burns from an acid spill will be counted on equal terms to third degree burns and fatalities from a vapour cloud explosion or toxic leak. This is not to say regularly occurring accidents involving corrosive burns should be ignored. This analysis may highlight the problem and give plant management the instigation to rectify the problem. It may be that corrosive burns are actually causing other significant problems with lost time, accident compensation levies and damage to plant. The acid load out bay represents the main sales area for the plant's primary product. If the equipment around the acid storage area is damaged, the plant may have to run on reduced capacity while equipment is being repaired or replaced. If staff are injured, replacement staff may have to be trained.

In this test site, plant management may wish to rectify the problem with the acid storage area by fitting a programmable logic controller (PLC) to facilitate the pump out routines. The frequency of PLC failure is one per 100 years. The results of the analysis of this new system are shown in example 2 (see Figure 6.2.1 for a summary and Appendix 5 for a full output). Here the acid storage index has been reduced to the magnitude of the sulphur burner and LPG cylinder. If these levels were used as an acceptability criteria, the sulphur melter compartment could then also be modified.

Figure 6.2.2 example 2 summary

sulphur melter index = 5.05

sulphur burner index = 0.13

LPG bullet index = 0.031

acid storage index = 0.13

site index = 5.34

In example 3 (see Figure 6.2.3 for a summary and Appendix 5 for a full output), the management have decided to increase the ventilation duct on the exhaust of the sulphur melter. Tests have shown that the increased duct size will reduce the frequency of duct blockage by an order of magnitude. They have also decided to reduce the LPG bullet capacity to 5 tonne in an effort to improve plant safety.

Figure 6.2.3 example 3 summary

sulphur melter index = 0.51

sulphur burner index = 0.13

LPG bullet index = 0.023

acid storage index = 13.23

site index = 13.89

The reduction in the LPG bullet capacity reduced the effect radius down to 150m (for the Whazan II analysis, see Appendix 11). This reduced the LPG bullet hazard index from 0.0311 to 0.0231. As this is not a significant reduction in hazardousness, the management may wish to retain the 10 tonne bullet, which will reduce the need for refilling and avoid the costs of swapping the LPG bullets. However, the change to the exhaust duct radius has reduced the melter hazard index to 0.5 persons seriously affected per 100 years. This is a significant improvement, especially considering that the alteration in the exhaust duct diameter can be achieved for low cost and minimal disruption to normal operating conditions. This example shows how a rapid ranking appraisal can quickly highlight the effects of plant modifications.

In example 4 (see Figure 6.2.4 for a summary and Appendix 5 for a full output), the management have decided to move the company's typing pool to the control room for two months, while part of the administration block is being redecorated. To pay for redecoration, management has decided to remove one flame detector from the LPG bullet. This will reduce the emergency response effectiveness to only "fair".

Figure 6.2.4 example 4 summary

sulphur melter index = 13.80

sulphur burner index = 0.22

LPG bullet index = 0.087

acid storage index = 13.23

site index = 27.34

The movement of staff further into the plant has increased the overall site index. These people will now be affected by the hazards from the sulphur melter, sulphur burner and the LPG bullet. The LPG bullet also has a reduced probability of effective emergency response. However, the LPG bullet index only increases to 0.0867. This example shows the sensitivity the method has for personnel location. In methods calculating hazard indices for other defined target groups, the sensitivity to their location would be similar because of the ability in the methodology to actively locate these target groups on a hazardous site.

It would be inappropriate to analyse the data in any more detail than above. The rapid ranking software is intended to rank the hazards in order for some kind of priority action and to indicate those areas on site where further investigation may be warranted. It can also be used to gauge the movement in hazardousness that accompanies modification or change in the installation. The analysis is simple and if a more sophisticated analysis is required, several of the techniques mentioned in chapter 2 could be used

6.3 Overlap discussion

In these analyses, it will be common for two effect radii to overlap. It is important to understand what this overlap means and what the overlap area hazardousness value will be. In the current software, the case for overlap is not considered.

For example, consider the situation in Figure 6.3.1, where there are two hazardous compartments on a site. For convenience, these shall be titled compartments #A and #B.

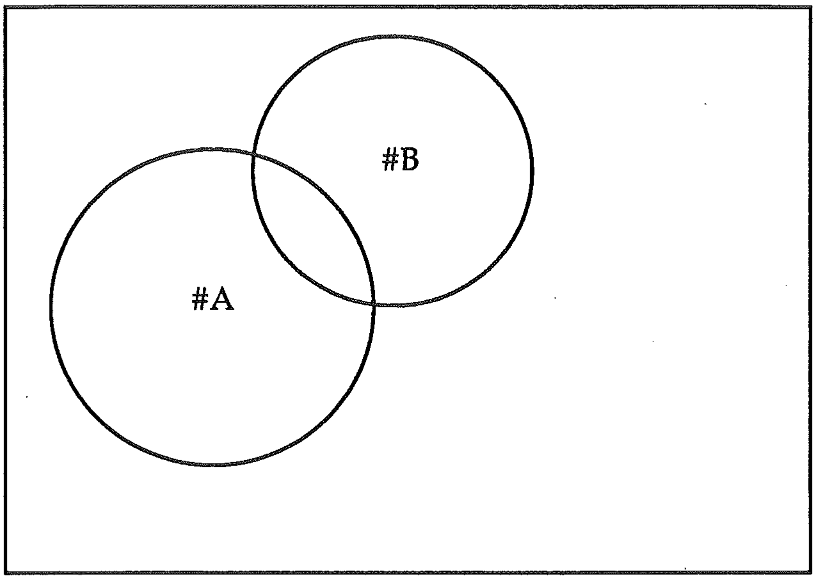


Figure 6.3.1 Overlap of Serious Effect Areas

In this case, their effect radii overlap, therefore the area in the overlap between #A and #B will potentially be affected by both hazardous compartments.

The individual compartment index is calculated by;

HI = frequency of failure (f) x probability of ineffective response (p) x numbers of people seriously affected (N)

= f.p.N

Therefore $HI_A = f_A.p_A.N_A$ and $HI_B = f_B.p_B.N_B$

As the hazardous compartments are considered independent, the effects can be added. It will be possible to add these effects because the individual hazard index represents that particular hazard's expected potential impact on that site. The overlap area will experience the effects from both hazardous compartments.

Therefore the overlap index will be HI_a plus HI_b (= HI_a AND HI_b plus HI_a OR HI_b)

As the number of people in the overlap will be static, only risk part of index (Risk = f.p) can be added.

$Risk_a = f_a.p_a$, $Risk_b = f_b.p_b$

$$Risk_a \text{ OR } Risk_b = Risk_a + Risk_b - Risk_a.Risk_b$$
$$= f_a.p_a + f_b.p_b - f_a.p_a.f_b.p_b$$

$$Risk_a \text{ AND } Risk_b = Risk_a.Risk_b$$
$$= f_a.p_a.f_b.p_b$$

$$Risk_a \text{ plus } Risk_b = f_a.p_a + f_b.p_b - f_a.p_a.f_b.p_b + f_a.p_a.f_b.p_b$$
$$= f_a.p_a + f_b.p_b$$

$$HI_a \text{ plus } HI_b = (f_a.p_a + f_b.p_b).\ N_{a \cap b}$$

$$HI_{1 \cap 2} = (f_1.p_1 + f_2.p_2).\ N_{1 \cap 2}$$

$$N_{1 \cap 2} = N_{1 \cap 2} \text{ (discrete)} + N_{1 \cap 2} \text{ (uniform)}$$

$N_{1 \cap 2}$ (discrete) can be seen from the screen, so input can be manual.

$N_{1 \cap 2}$ (uniform) = $Area_{1 \cap 2}$. personnel density

Therefore, to calculate the overlap index, the area of overlap must be calculated. The method used to calculate the overlap area is derived in Appendix 7 and theta, the software designed to calculate the overlap area is explained in Appendix 8, with a software listing in Appendix 9.

To better understand the effect of overlap, consider the case of overlap between two compartments, 1 and 2 in Figure 6.3.2.

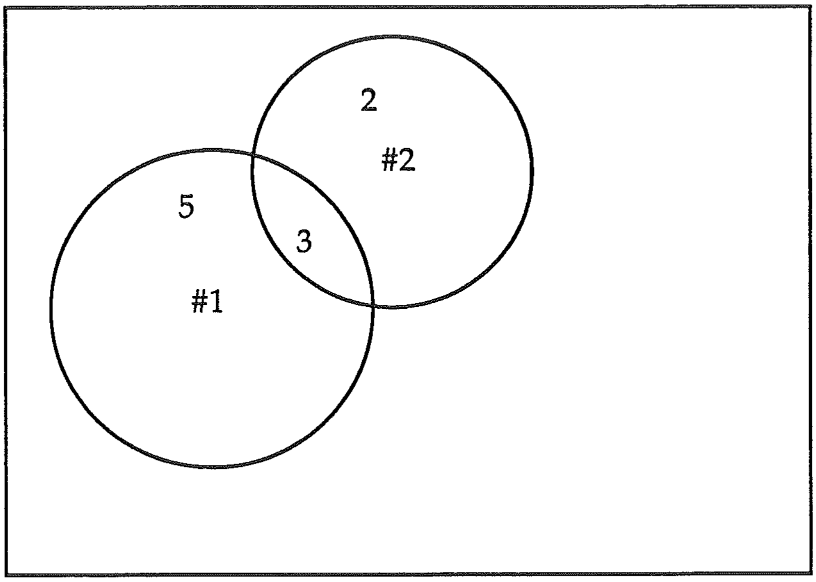


Figure 6.3.2 Case Example of Site Overlap

Site data input: ra (r1) = 100m, rb (r2) = 80m, ab = 140m; personnel density = 0.0003 people/m^2. There are eight people affected by #1, Five affected by #2 and three within the overlap area between #1 and #2.

Assume $f_1.p_1 = 1$ and $f_2.p_2 = 2.5$.

The Area of #1 = 31416m^2, the Area of #2 = 20106m^2.

From the software Theta (refer to Appendix 9), $\varnothing_1 = 34.1°$, $\varnothing_2 = 43.4°$, **Area$_{1\cap 2}$ = 3069m^2.**

HI	= f.p.N	
HI_1	= 1 x (5 + 3 + 0.0003 x 31416)	**= 17.42**
HI_2	= 2.5 x (3 + 2 + 0.0003 x 20106)	**= 27.58**

$$HI_{1\cap 2} = (f_1.p_1 + f_2.p_2) \times (3 + 0.0003 \times Area_{1\cap 2})$$
$$= 3.5 \times (3.92) \qquad = \mathbf{13.72}$$

This analysis shows that the overlap area is actually less hazardous than the individual effect circles. If the severity of the hazards impact were measured against property or the environment, the analysis may yield different results. The results from this analysis will also change with different personnel locations.

The effect radii will describe an area around a hazardous component, where the number of people contained can be summed to give an estimate of the numbers affected by that hazard. The radii are not used as hazardous distances, although they are derived as hazardous distances from models in Whazan II. However, that distance has no meaning in the context of hazard index calculation.

The effect area will have uniform risk (as defined by the product of frequency of failure and the probability of ineffective response), but will not have uniform hazardousness. In the example above, the risk within $Area_1$ was 1, while the risk within $Area_2$ was 2.5, giving a risk within the overlap area of 1 + 2.5 = 3.5 (units unspecified for this example). Hazardousness is not uniform because the project methodology allows non-uniform (discrete) placement of personnel and calculation of the numbers of uniformly distributed people affected will use the overlap area. The overlap area will invariably be small in comparison to the main hazard area, and will give correspondingly small numbers of uniformly distributed personnel within. In any case, hazardousness cannot be defined for an area. The hazardousness will be attributed to the hazardous compartment, as it will be to the encompassing site. It is easier to visualise the circular areas described by the effect radii as risk templates that can be directly applied to a target group within, in this case personnel. In the case of the hazardous compartment's impact on property or the environment, a suitable criteria will be decided upon, then respective effect radii will be estimated and interaction between the template and that group will indicate that particular variant of hazardousness.

Hazard indices can only be added when the summed value is not attributed to a specific geometric area, as in the case of the combined site index. When two or more hazard indices is summed to calculate the hazardousness of an overlap, the numbers of people affected are being counted more than once. Instead, the overlap will contain a target group with the potential to be exposed to more than one hazard. In other words, the target will experience the hazardous effects from both compartments to some degree. The calculation of overlap hazardousness does not deal exclusively with the impact of both hazards occurring at the same time. Instead it is an estimation of the impact the area within the overlap will experience from two or more hazards within the 100 year time frame. When estimating the hazardousness of an overlap area, this increased potential for hazard exposure is what we wish to ascribe to that area.

Adding hazard indices for a combined site index is allowable because it is a general estimate of the hazardousness that the site will expect to experience over 100 years. Specific overlap area contributions are not being counted, nor is that site index related to any specific piece of ground. The site index is a non-specific general value for the overall site hazardousness that can be used to indicate the quality of overall plant safety, through comparison with other sites or the same site after a period of time.

The major problem of overlap analysis is that while the software in Appendix 9 can deal adequately with an overlap of two radii, it cannot deal with overlaps of three or more (i.e. $a \cap b \cap c$). The geometry of this situation is much more complex and due to the time estimated to develop a proof for overlaps of three of more surfaces, further investigation on the overlap of effect radii was discontinued.

6.4 Comparison with the Dow Fire and Explosion Index

The Dow Fire and Explosion Index system (Dow Chemical Company, 1987) is a step by step approach to rate the risks of fire and explosion hazards in process installations. The Fire and Explosion Index is a product of risk values covering General Process Hazards, Special Process Hazards and a Material Factor. The General Process Hazards are derived from those hazards common to that particular process. The Special Process Hazards cover hazards arising from the physical conditions that the material(s) in the process are held in and the process working environment. The Material Factor indicates the propensity of a material to be involved in a hazardous situation involving fire or explosion and is derived from the NFPA 704 (NFPA, 1990) values of Nf and Nr, representing indices for relative flammability and reactivity. The Dow system was chosen to validate the hazard ranking software developed in this project because it is a internationally accepted method of hazards analysis, it employs a risk ranking type of technique and it is simple to apply.

As mentioned, the Dow index deals primarily with fires and explosions. the only compartment in the test case that had a risk of fire or explosion was the LPG bullet. Toxicity is covered in the index, but only in the section on Special Process Hazards where the contribution of the NFPA toxicity index Nh (NFPA, 1990) is only one of 14 elements in the section. Toxicity has no contribution in the Material Factor, which is a major multiplier within the index. In the test site used in this project, four materials were used. These were hydrogen sulphide (liberated from sulphur in the sulphur melter), sulphur dioxide (escaping from the exit of the sulphur burner), propane (from the LPG bullet) and sulphuric acid (escaping from the acid storage tanks). Propane and hydrogen sulphide were given material factors of 21, while sulphur dioxide and sulphuric acid were given material factors of 1. Concentrated sulphuric acid is not particularly toxic or mobile, but sulphur dioxide has a WES (STEL) of 5ppm (Department of Labour 1992), one third the recommended exposure of hydrogen sulphide at 15ppm (Department of Labour 1992). Hydrogen sulphide is given a higher material factor because it is a flammable gas.

This contributed to the disparity of the fire and explosion indices shown in summary in Figure 6.4.1 (see full Dow Analysis sheets in Appendix 14).

Table 6.4.1 Comparison of Dow Fire and Explosion Indices and Hazard Indices

Process Unit	Dow Fire and Explosion Index	Hazard Index
sulphur melter	137.7	5.05
sulphur burner	3.3	0.13
LPG bullet	112.9	0.031
acid storage	3.135	13.23

It is easier to compare the two methods by examining both the positive and negative aspects of each method. The Dow method is probably the more reliable method. The steps involved in calculating the index are more numerous and detailed. While the method is somewhat arbitrary in its approach, the structure to the method gives the user well set guidelines in using the method and high reproducibility of results. The years of development by Dow Chemical Corporation also mean that the method is refined and based on considerable experience. The derivation of material factors from NFPA 704 reinforces this experienced and trustworthy approach. While the method deals exclusively with risks from fires and explosions, it does so thoroughly. Consideration is made at all facets of the production environment and a range of fires and explosions are covered, including dust explosions.

Aside from the lack of toxicity impact on the Dow index, the software designed in this project would give the most realistic ranking. Rapid ranking methods are used on industrial sites as the first step in identifying particularly hazardous areas or agglomerations of hazards. This allows resources to be allocated most effectively in the control of these hazards, be that control through, new hardware, new software or simply more attention. The rapid ranking software in this project takes account of the frequencies of failure events, as well as available mitigation and the consequences. The embodiment of a time related value in the project hazard index brings an element of risk into the analysis, which is essential for prioritisation of industrial hazards. The software may highlight a low consequence event that happens once per year, instead of concentrating on potentially catastrophic events that may occur once in 10^7 years. In a plant with an operating life of 25 years, the low consequence event is going to do more to disrupt work, injure people and cause down-time, thus its control can become the higher priority (depending on how practical the control procedure is). The project software can help set this priority through its ranking process. The project software will also reflect changes made to the plant hardware and software faster.

There are two other elements of the Dow index method which have application in a comparison with the project method. The loss control credit factors are a series of mitigation elements that the method user can indicate are present in the site being analysed. Aligned to each element is a number that represents the degree to which that element can help mitigate an undesirable incident (these numbers are usually nominally less than one). The loss control credit factors are grouped under three headings, namely Process Control, Material Isolation and Fire Protection. For the process unit analysed, these factors are multiplied together to give a unit credit factor. These factors are similar in intention to the index for probability of an effective response used in the project method. When comparing the loss control credit factors for each process unit analysed with the mitigation probability chosen (Refer to Table 6.4.2), there is a certain relativity between the data, but this does more to reinforce that the initial choices for mitigation probability were correct.

Table 6.4.2 Comparison of Loss Control Credit Factors From Dow Method With Chosen Probabilities of Effective Response

Process Unit	Loss Control Credit	Probability Choice
Sulphur melter	0.866	0.5
Sulphur burner	0.805	0.5
LPG bullet	0.73	0.2
Acid storage	0.95	0.2

The other element of the Dow method worthy of mention is the Area of Exposure. The Area of Exposure (actually given as a radius) is the area containing equipment that could be exposed to a fire or a fuel-air explosion generated in the process unit being evaluated. The area is calculated from a radius of exposure which is 0.84 x the Fire and Explosion Index (in feet). Like the areas calculated by the project software, this area is a simplified circle around the process unit. In Table 6.4.3 the Dow Areas of Exposure are compared with the radii of serious effect generated from the Whazan II data and used as input data in the project software.

Table 6.4.3 Comparison Between Dow Area (Radius) of Exposure and Radius of Serious Effect Derived From Whazan II.

Process Unit	Area of Exp. (ft)	Area of Exp. (m)	Radius of Serious Effect (m)
Sulphur melter	115.7	35	50
Sulphur burner	2.772	0.84	80
LPG bullet	94.8	28.9	180
Acid storage	2.63	0.72	20

From the definition of the Area of Exposure, there is obviously a low chance of a fire developing around the acid storage tanks, even to a radius of 0.72m. Admittedly, Table 6.4.3 is displaying Dow Index data in a form that was not intended, by comparing them to analyses that have taken toxicity into account. It is still worthwhile displaying the data, for the sake of comparing the indices for the LPG bullet. The Whazan II data gives an effect distance 6x that of the Dow data. The criteria for consequences in this project, cited in chapter 5.5 are set at a reasonably low impact and take no account of site topography. The criteria for the Dow Area of Exposure is based on estimations of plant damage. Considering the experience in the method and the operating history of the Dow Chemical Corporation, one could assume that the distances are of a realistic magnitude for that purpose. The Dow Area of Exposure could therefore be used within the project method to estimate the impacts on property within the site, if that were the impact target group.

7.0 CHANGES AND MODIFICATIONS

The suggested modifications to this software come under three categories.

7.1 Basic Improvements

The first category for modification are those changes that could be done to fine tune the current software. These will include the modifying of current subroutines, adding new routine and making the execution of code more efficient. These modifications are the minimum required for widespread commercial use of the software.

To tidy up the software, the opportunities to have entry data corrected should be spread through the entire package. At the moment, only the site boundary data can be corrected. However, it could be argued that because of the simplicity of the software, an incorrect entry would only mean re-running the software, with nothing but a few minutes time lost. Validation routines for data could also be put in throughout the software. Only site and compartment entries are validated at the moment. If incorrect entries are put in for personnel positions, or personnel numbers an incorrect analysis will result. In the cases stated, either personnel will be placed off the screen or the incorrect numbers of personnel will cause an erroneous result. Validation is not used throughout the current version of the code because it is time consuming during software execution.

The opportunity to be able to retrieve data from files and review it would also be useful. File retrieval software would not be difficult to write and there is also the opportunity to review the output files from more than one site at a time. In the current form of the software, its simplicity would probably preclude any meaningful comparison, but it may be worth considering for further versions.

One obvious route for modification is to calculate a hazard index that would have contributions for the impacts on the plant and equipment on site and on the environment, as per the original Tweeddale and Keey methodologies. Considering that this software is being produced for the small New Zealand industry, it is reasonable to assume that identifying ways to minimise plant damage and full compliance with the relevant sections of the Resource Management Act, 1991 (Parliamentary Counsel Office 1991) are going to be of considerable importance to the management of these sites.

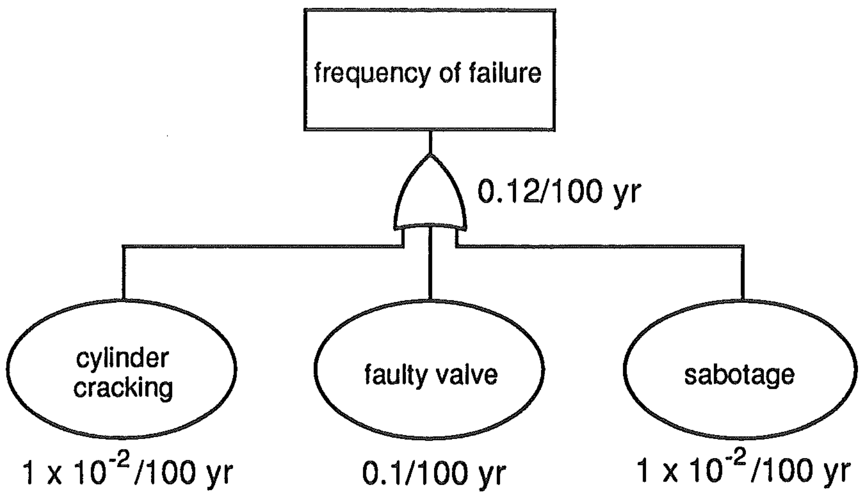
In the current software version, the severity index is the only component of the hazard index that uses a more complex analysis (using consequence analysis from Whazan II with direct positioning of personnel on site to estimate personnel impacts). It would also be possible to aid the user in the selection of the indices for the frequency of failure and the probability of ineffective response. One type of technique could be considered to aid the selection of both these values because they both represent the likelihood of an undesirable event occurring.

The technique used most often in the analysis of likelihoods is fault tree analysis, thus it could be used to help the analysis of the frequency of failure and mitigation probability index components. In the case of the frequency of failure, the user could define the main compartment failure as the top event on the fault tree. The contributing events to that failure could then be broken down to individual failures. The values assigned to these individual failures could be derived from the descriptor tables. This type of analysis would adjust the failure frequency values slightly, and could also increase the understanding of the effects of the contributing failure modes. Accident records could also be used, along with hazard warning analysis to further improve these final frequency values.

In the case of estimation of mitigation probabilities, the table would be set up with the mitigation devices available. The probability of total mitigation failure would be derived from the individual probabilities in the descriptor tables. The use of fault trees is especially suited to the calculation of mitigation failure probabilities because of the need to calculate for the effects of multiple mitigation devices.

One case would be the estimation of the failure frequencies and mitigation probabilities concerning the possibility of a propane cylinder exploding into a fireball (bleve). A simple estimate of the contributing likelihoods is shown on Figures 7.1 and 7.2.

Figure 7.1 Frequency Of Failure For Bleve



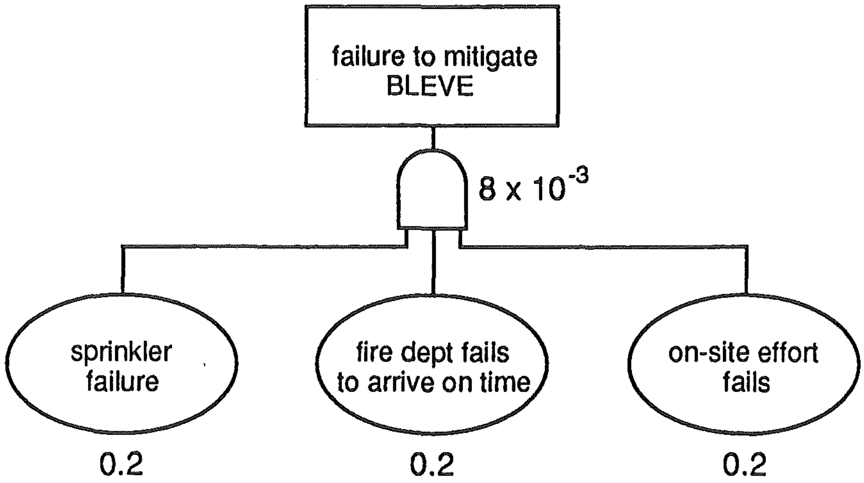


Figure 7.2. Probability Of Ineffective Response In Case Of Bleve

A routine to use this analysis would be reasonably simple to add to the project software. The analysis could be kept to limited complexity by setting the number of tree levels to two and the number of branches to three.

These changes are aimed to help the user in the selection of index components. They improve the user's understanding of the hazards, without adding to the complexity of the use of the software. Thus they do not lead to an over analysis and retain the simplicity of method in of this project. Flow diagrams to show approximate procedures for these routines are shown in Appendix 10.

The diagrams used in this section are done using software produced by Arthur. D Little Ltd. Faultrease is primarily a graphic display tool for fault tree analysis. The software used for this project was Apple Macintosh compatible. Faultrease allows the user to build up a fault tree, setting likelihood values at contributing 'leaves'. The format is user friendly with the reorganisation of branches of the tree known as pruning and grafting. The top event likelihood can be calculated at any time, using the Boolean operators.

7.2 New Programming Software

The next category involves the transfer of the methodology into a more sophisticated software environment. The focus will be based around modifications that could be achieved with new programming software that were difficult or impossible to achieve using Microsoft Quickbasic.

The choice of new programming software is varied. A purpose designed relational database could be used. It could be considered that because of the simple mathematical operations used in the methodology, a data base is more important to hold site data. Using a relational database would mean that an on-line failure frequency database could be built in to the software, with failure data being entered automatically as soon as corresponding plant equipment were specified. The biggest failing for a relational database would be the lack of graphics capability. If graphics capability were deemed important, other more sophisticated types of software could be used. Example of these are Pascal or C. These languages are both as portable as Microsoft Quickbasic, but are more sophisticated in their approach and have a more useful graphics capability. There are also commercial library routines available that would link such software to relational data bases. Unfortunately, this makes the finished software quite expensive and somewhat cumbersome.

The amalgamation of an on line consequence package would also be useful. This would avoid the current situation where the consequence package has to be run on a different type of computer, using different software. A totally new consequence package would not be necessary as it was never the aim of the project to re-invent the wheel. The best solution would be to design software to interface with the likes of the Whazan II software.

7.3 A New Methodology

The third category is to approach the same initial aims of the project (Software that is developed for the New Zealand industry scale, easy to use and inexpensive.), with a different methodology. These suggestions will be made with the benefit of the time spent on this project.

The sophistication of the software could be improved significantly by adopting a shell type of approach. The first shell would be the analysis in the current methodology. This would indicate the high hazard compartments on a specific site. The next layer in the shell would be to consider that compartment in the same fashion that the software considered the whole site in the first shell. This would be to seek out the contributing factors that caused that hazard rating. This shell approach could continue toward a breakdown of pipes, valves and flanges. An approach of this type of approach would also amalgamate many of the broader modifications suggested in this chapter.

Another way to extend the methodology to adopt a shell analysis, would be to extend the approach of Lapp (1990). The method would be to continue the fault tree analysis downward through the contributing branches, in an effort to refine the result for the top event value. One or all of the compartment indices could be further analysed this way. With respect to encoding of the method, further application would be simple, once the routines for the Boolean operations were written. The scope for this analysis would also be down to the pipe and valve level.

The final suggestion for change would be the implementation of an expert system. Using a very sophisticated (fourth or fifth generation) language, the emphasis of the software could be radically changed. Obviously in this case, the expense could not be kept so low, but an expert system has the advantage of enhancing user friendliness.

8.0 HUMAN FACTORS AND RISK MODIFICATION

8.1 Limitations of Analysis

While the benefits of the quantitative analysis of hazards have been discussed in this document, Tweeddale (1992) warns of too much faith in the infallibility of quantitative results. Serious misjudgement can occur when management consider a complex quantified analysis of a system to hold all the answers, without considering those elements that cannot be quantified. Thus the pendulum can either swing back to qualitative analysis, or the consideration of new analytical techniques not previously thought to be under the umbrella of quantified analysis. Tweeddale states that a hazard evaluation depends more on the estimation of management effectiveness than on hardware failures that can be estimated using quantitative methods. However, the distinction is not sharp, generic failure rates in the literature implicitly embody management factors.

In the conclusion of the reports prepared by the CONCAWE study group (Hope 1984b), limits were defined on the use of numerical hazard data. The data were thought to have limitations in three main areas. First, the actual performance of a new plant may differ from that at the design stage, indeed the performance will be changed through any modification. Thus any data must be reviewed to take account of these changes. The next point was that the analysis is only as good as those features that are analysed. The report warned that care should be taken in disregarding failure events because low likelihood or because of a lack of understanding of the mode(s) of failure. Finally, the report states that the human response to unexpected events is difficult to predict, although techniques such as task analysis can yield estimates which are consistent with operator error rates that have been observed.

8.2 Human Error and Plant 'Software'

It is widely accepted that a large number of major accidents result from unpredictable human errors. There are many different types of human error defined (Advisory Committee on the Safety of Nuclear Installations, 1991), but they are usually either caused by the operator acting incorrectly or not at all. It is more difficult to assess the reliability of an operator to get valid reliability data. Human operators are all unique and fill a far wider spectrum of reliability than valves or pipe flanges. However, in most practical instances, human reliability will fall within a range depending on the speed of response, quality of operator training, situational stress and ergonomic factors. These factors are known within error bounds.

In the defined methodology and software, human factors are not explicitly taken into account. In recent years, studies (HMSO 1991) have been conducted to estimate the effects of human error on risk values. Indeed, data from these studies have been amalgamated into the process of quantitative assessment. These studies attempt to identify all points within a system where incorrect human action may lead to adverse consequences.

8.3 Use of Risk Modifiers

There have been suggestions to use some semi-quantitative descriptors to calculate risk modifiers, taking account of the 'software ' within the plant. This 'software' will include the quality of management, operational staff and how the plant hardware interacts with the operators. Tweeddale (1992) presents mixed views on this. On one hand he argues that the use of generic multipliers is inappropriate because accidents do not result from the average performance of a worker. Instead, they result from particular instances, usually involving abnormalities. Tweeddale concludes with a case for generic multipliers, noting that while the multiplier may only be an arbitrary midpoint, the magnitude of any fine tuning would be even more arbitrary. Instead, a qualifying statement could be supplied with the analysis, stating that the values calculated could be expected to be either better or worse that the stated value.

In the calculation of the hazard indices for this project, these generic multipliers could have a significant use. The mode of index calculation is reasonably simple, with hazard relativity being the main aim. Thus the use of multipliers would convey to the analyst user to give more of a 'feel' for the hazards within the plant. Simplicity of the index calculation methodology also means that the use of the multiplier will not over quantify the indices. Clearly, the quantification of hazards cannot replace the pursuit of widespread understanding of the hazards on site and the means to control them.

In his summary of rapid ranking techniques, Bennet (1992) discusses an example of a method of introducing a management factor to hazard scores calculated. The management factor is in the form of a multiplier to the calculated hazard index. This method rates the quality of specified elements of that site's safety management system.

In Bennet's example the quality of four elements in a safety management system are rated. These elements will all have a bearing on how effectively the human worker will be able to relate to the requirements of its job. The elements are; Training procedures, Maintenance of plant and instruments, Instrument and control systems, and Safety management. These elements are then graded against descriptors for their performance within the site.

The use of descriptors mirrors the simplicity of the methodology and software produced in this project, thus it could be considered an appropriate addition. In the appendix (see Appendix 12) is a short subroutine that can be used to calculate these management factors. It could be added on to the main code if required. The descriptors are shown in Table 8.3.1.

Table 8.3.1 Descriptors For Management Qualities

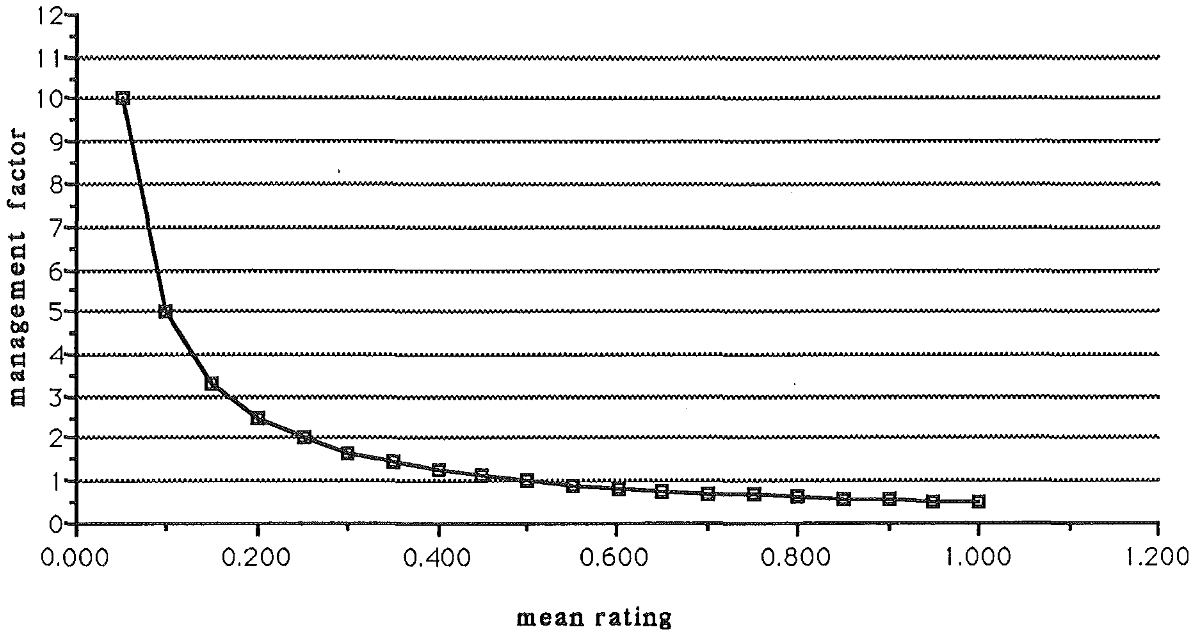
DESCRIPTOR	NUMERICAL RATING
Poor	0
Fair	.2
Average	.5
Good	.8
Excellent	1.0

The equation for calculation of management factors is shown in equation 8.3.2

8.3.2
$$managementfactor = \frac{1}{\sum_{j=1}^{m}(weighting * rating_j)}$$

Where m is the number of safety management elements, in this case four. In his method, Bennet used weightings of 0.5. This means that if all of the descriptors are given as average the management factor is calculated as 1.0. With the weightings and numerical ratings for this model, management factors have a useable range between 0.5 and 10 (the management factor is infinite for consistent ratings of poor), as shown in Figure 8.3.3.

Figure 8.3.3. Variation of management factor vs mean rating



The management factor can be used on the site index as a summary of plant management, or as a multiplier to the individual compartment indices, where qualities of hardware and software vary throughout the plant.

To show the application of management factor multipliers, consider a case example used in the analysis for this project. In the first example of the test site (see Appendix 5), the index calculated for the acid storage area was 13.23. If the training on the site was 'poor', if the maintenance at the acid storage area was 'fair', the instrumentation 'average' and the overall safety management 'average', the management factor would be 1.66. Thus the management adjusted index would be elevated to 21.96. The units of this index would not remain as persons affected per 100 years. The index has now embodied the qualitative 'software' elements of the site. The index is potentially more useful in the information it contains. In this example, the problems associated with having poorly trained staff are amplified. In the example 2 of the software output (see Appendix 5), the frequency of the failure at the acid storage tanks was reduced to 0.13 by installing a PLC. While this aspect of the effect poorly trained staff have on a site has been negated, the implementation of the management factor will still note that the staff are poorly trained and have the capacity to elevate the hazard index. This is an important point to note, that 'software' and 'hardware' failures will usually work independently, so that only rectifying the source of the problem will alleviate its effects.

9.0 CONCLUSIONS

The basic methodology, derived from the work of Tweeddale and Keey proved to a good base for this project. While the process of calculating hazard indices was simple, the contributing parts of the index were three prime contributors to the hazardousness of an industrial installation. Decisions made by the user on the magnitude of those factors use would improve their perspective of the hazards involved.

The software designed, using the methodology analysed a site quickly and a gave a useful hard copy of result data. The Whazan II software provided raw consequence data for the derivation of serious effect distances in a form that was easy to relate to the set vulnerability criteria, although it does not deal with hazards such as dust explosions.

Analysis of effect area overlaps allowed a better perception of the hazard index, regarding the relationship between compartment hazardousness to the site topography. The use of a non-uniform distribution of the target impact group forced a distinction between the risk part of the index and the outcome on that target group. Risk could be uniformly distributed within the area described by the effect radius, but the target group remained as discrete units. This meant that while risk could be attributed to areas defined on the site, the hazardousness could only be attributed to the hazard causing compartment.

When the project hazard indices for the test site were compared with Dow Fire and Explosion Indices for the same site, a favourable comparison was made. It was recognised that the Dow index had minimal contribution for toxic effects, thus a direct comparison of indices was not particularly useful. However, application of both methods was useful in comparing their approach, execution and respective limiting factors. The Dow index is based on a wealth of experience in the Dow Chemical Corporation. The analyses and correlations with the Dow Fire and Explosion Index method, are based on the corporation's experience, and are thus somewhat arbitrary. The arbitrary approach means that the results are with certain bounds of empirical expectation. This coupled with the structured, multiple element approach, means that the method is extremely reliable and that resultant index data is highly reproducible.

The project software gives realistic results. The main aim of a ranking process is to provide a means of prioritising hazards in workplace so that resources can be allocated to most effectively control those hazards. The project software has the ability to measure the impact of toxic hazards, and more importantly gives an impression of the risk involved, through its use of a time related element in the frequency of failure. Risk sets the basis for prioritisation in these matters. The Dow index is more of a loss prevention system, as its final analysis works toward assessing property damage and the resulting costs. With only the impact on persons considered, the project software is a safety package only. However, analysis techniques regarding property damage assessment, similar to those within the Dow method could be integrated into the project software for that purpose.

Overall, the software satisfies the initial aims of the project, in that it responds to the needs of the breadth of New Zealand industries. It is simple to use, can run on a minimal amount of computer hardware (as an executable file) and provides hard copy output. The results from the software analysis can be used to identify hazardous areas or compartments on site. The graphic image capability on the screen and hard copy enables the user to see if several of these compartments are agglomerated in a certain area on the site. Thus, the basic requirements of a rapid ranking method are satisfied. Hazards can be effectively prioritised, as an indication of their effects has been gained.

The software produced is not perfect, nor is it instantly ready for marketing as a hazard appraisal system for smaller New Zealand industries. The software has been written as a tool for analysis of the methodology in this project. An attempt has been made at user-friendliness, but by no means the degree necessary for commercial exploitation. The programming software could also be changed to a more sophisticated type, which would ease any cosmetic changes mentioned earlier.

The prime value of the project software is that it provides a base for further development and testing of rapid ranking software. Further investigation could use the suggestions mentioned in this thesis. It successfully embodies the project aims and could be useful to industry and regulatory authority alike.

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REFERENCES

Advisory Committee on the Safety of Nuclear Installations. Study Group on Human Factors; Second Report: Human Reliability Assessment - a critical overview. HSC, HMSO (1991) London

Barker, John Accident Investigation - Get The Facts With Fault Tree Analysis. Accident Investigation (December 1990), pp7-11

Bennet, Anthony J Rapid Ranking Of Process Hazards. Department Of Chemical And Process Engineering, University Of Canterbury, (1992)

Chidambariah, Venkatesh et al A relative risk index for prioritisation of inactive storage tanks. Journal of Hazardous Materials, 27 (1991) pp327-337

Corran, E.R Analysis And Assessment Of Industrial Risk - An Overview. The Journal Of Occupational Health And Safety -Australia And New Zealand (1987), pp136-143

Department of Environment and Planning, Sydney. A Risk Assessment For The Kurnell Peninsula. Department of Environment and Planning (1986), Sydney

Department of Labour. Workplace Exposure Standards and Biological Exposure Indices for New Zealand. (1992), Government Print, Wellington.

Dow Chemical Company. Fire And Explosion Index Hazard Classification Guide. Dow Chemical Company, 6th Edn (1987)

DNV Technica Ltd. Whazan Version 2 User Manual. Technica (1992), London

GCNZ Consultants, H. M Tweeddale Consulting. Rosebank Peninsular Risk Assessment Study. GCNZ Consulants Auckland (1989), pp26-76

Gieck, Kurt J A Collection of Technical Formulae. Gieck-Verlag, 6th Edn West Germany (1985), pB3

Gressel, Michael G and Gideon, James A. An Overview Of Process Hazard Evaluation Techniques. American Industrial Hygiene Association Journal; 52(4) (April 1991) pp158-163

Health and Safety Executive. A guide to the Control of Industrial Major Accident Hazards Regulations 1984. HMSO (1985), London

Health and Safety Executive. Risk Criteria For Land Use Planning In The Vicinity Of Major Industrial Hazards. HMSO (1989), London

Hope S et al Methodologies For Hazard Analysis And Risk Assessment In Petroleum Refining And Storage Industry - Part 1 (CONCAWE). Fire Technology, Vol 20 (1984a) pp23-38

Hope, S et al Methodologies For Hazard Analysis And Risk Assessment In Petroleum Refining And Storage Industry - Part 2 (CONCAWE). Fire Technology, Vol 20 (1984b) pp43-56

Hurst, N.W et al Development and Application of a Risk Assessment Tool (RISKAT) in the Health And Safety Executive. Chemical Engineering Research and Design, Vol 67 (July 1989) IChem E, London pp362-372

International Labour Office. Prevention of Major Accidents. ILO (1991), Geneva. pp5

Keey, R.B Reliability in the Process Industries. Institution of Professional Engineers New Zealand (1987), Wellington

Keey, R.B A rapid hazard assessment method for smaller scale industries. Trans I Chem E, Vol 69 Part B (May 1991a) pp85-89

Keey, R.B Safety and Reliability Course notes University of Canterbury (1991b)

Keey, R.B Private Communication (1992)

Lapp, Steven A. The Major Risk Index System. Plant / Operations Progress, Vol 9 No 3 (July 1990) pp176-180

Lees, F.P Loss prevention in the Process Industries; Vol 1&2; Butterworths (1980) London

Liquid Fuels Trust Board. Risk Assessment of Proposed Liquigas Ltd LPG Bulk Storage and Distribution Facilities. Liquid Fuels Trust Board (1982), Wellington

Major Hazards Assessment Panel. The effects of explosions in the process industries. I Chem E (1989), London

National Fire Prevention Association (NFPA). NFPA 704; Standard System For Identification Of The Fire Hazards Of Materials. NFPA (1990) Quincy, USA

New Zealand Commission of Inquiry. Report of the Commission of Inquiry into the Explosion and Fire which occurred at the General Plastics (NZ) Ltd on 26 September 1974. Government Print (1975), Wellington

Parliamentary Counsel Office. Accident Rehabilitation and Compensation Insurance Act (1992a). Wellington

Parliamentary Counsel Office. Health and Safety in Employment Act (1992b). Wellington

Parliamentary Council Office. Resource Management Act (1991). Wellington

Perry, Robert H. and Chilton, Cecil H. Chemical Engineers Handbook Fifth Edition, McGraw Hill (1983) USA pp3-6 - 3-45

Pickford, G and Corran, E.R Techniques of Hazard Identification. <u>In</u> Warren Technical Reports, Warren Centre For Advanced Engineering, University of Sydney, Sydney (1986), pp B1 10

Pitblado, R.M and Nalpanis P. Quantitative Assessment of Major Hazard Installations - Computer Programs. <u>In</u> Lees, F.P and Ang M.L Safety

Cases - within the Control of Industrial Major Accident Hazards (CIMAH) Regulations 1984, Butterworths (1989) London pp175-179

Schofield, C. Guide to Explosion Venting, Prevention and Protection - Part 1 Venting. I Chem E (1985), London

Technica Ltd, World Bank. Manual Of Industrial Hazard Assessment Techniques. World Bank (1985), USA.

Tweeddale H.M. Balancing Quantitative and Non-Quantitative Risk Assessment. Volume 70 Number B2, Trans I Chem E Part B (May 1992), pp70-74

Walker, I K Occupational Safety. State Services Commission (1981), Wellington

Wood S and Tweeddale, H.M Rosebank Peninsula Risk Assessment Study - A Review Of Safety And Risks In An Auckland Industrial Area. Proceedings IPENZ Conference (November 1989), Wellington pp51-61.

APPENDICES

Appendix 1. Consequence Tables

TABLE A1.1 Consequences of Heat Radiation

(Dept of Environmental Planning 1986)

Heat Radiation (kW/m^2)	Effect
1.2	Received from the sun at noon in summer.
2.1	Minimum to cause pain after 1 minute.
4.7	Will cause pain in 15-20 seconds and injury after 30 seconds exposure (will cause 2° burns).
12.6	30% chance of fatality for continuous exposure. Will cause the temperature of wood to increase to a point where it can be ignited by a naked flame after long exposure. Thin steel with insulation on the side away from the fire may reach a thermal stress level high enough to cause structural failure.
23	100% chance of fatality for continuous exposure to people and 10% chance of fatality for instantaneous exposure. Spontaneous ignition of wood after long exposure. Unprotected steel will reach thermal stress temperatures sufficient to cause failure. Pressure vessel will need to be relieved or failure would occur.
35	Cellulosic material will pilot ignite within 1 minutes exposure. 25% chance of fatality if people are exposed instantaneously.
60	100% chance of fatality for instantaneous exposure.

TABLE A1.2 Effects of Explosion Overpressure

(Dept of Environmental Planning 1986)

Explosion Overpressure	Effect
3.5 kPa (0.5 psi)	90% glass breakage. No fatalities and very low probability of injury.
7.kPa (1 psi)	Damage to internal partitions and joinery, but can be prepared. Probability of injury is 10%, no fatality.
14 kPa (2 psi)	House uninhabitable and badly cracked.
21 kPa (3 psi)	Reinforced structures distort. Storage tanks fail. 20% chance of fatality to a person in a building.
35 kPa (5 psi)	House uninhabitable. Wagons and plant items overturned. Threshold of eardrum damage. 50% chance of fatality for a person in a building and 15% chance of fatality fro a person in the open.
70 kPa (10 psi)	Threshold of lung damage. 100% chance of fatality for a person in a building or in the open. Complete demolition of houses.

Appendix 2. Software listing - Hazrank

To aid the interpretation of the software, refer to Appendix 3 for a list of variable explanations and Appendix 4 for a quick reference of subroutine explanations.

```
REM INTRODUCTION, INITIALISE AND TITLE
GOSUB START

REM ENTER RELEVANT DATA
GOSUB ENTERSITE
GOSUB INPUTPEOPLE
GOSUB ENTERCOMP

REM MAIN LOOP FOR INDEX CALCULATION
GOSUB ENTFREQ

REM PRINTS REPORT TO SCREEN AND CLIPBOARD
GOSUB FINAL

END

START:
REM INITIALISE
d=0:pi=3.1416
DIM cx(20),cy(20), rad(20),yy(20),xx(20)
DIM com$(20), num(20), pers(20), px(20), py(20)
DIM fredis$(15),freval(20),freq(20), sh(20)
DIM hi(20), fa(20), fm(20), mit(20), mitdis$(20), mitpro(20)
REM READ IN DATA STATEMENTS
```

```
FOR i=1 TO 7: READ fredis$(i):READ freval(i):NEXT i
FOR i=1 TO 5:READ mitdis$(i):READ mitpro(i):NEXT i
REM TITLE PAGE
CLS
LOCATE 4,9:PRINT "HAZARD RANKING ANALYSIS SOFTWARE"
LOCATE 8,12:PRINT "by Kevin Sanders"
LOCATE 18,38:PRINT "press space bar to continue"
WHILE INKEY$ <>" ":WEND
CLS:PRINT :PRINT :INPUT"PLEASE ENTER NAME OF SITE";site$
PRINT :PRINT :PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
CLS
RETURN

ENTERSITE:
REM ENTER SITE BOUNDARY COORDINATES
WHILE q$<>"n"
d=d+1:flag=1
WHILE flag=1
flag=0
LINE (0,0)-(495,262),0,bf
d=d-1:GOSUB GRIDPRT:d=d+1
LOCATE 17,30:INPUT"Please enter x coord";xx(d)
LOCATE 18,30:INPUT"Please enter y coord";yy(d)
IF xx(d) >10 OR xx(d)<0 THEN flag=1
IF yy(d) >10 OR yy(d)<0 THEN flag=1
LINE(0,230)-(495,295),0,bf
IF flag=1 THEN PRINT "value outside, repeat entry"
WEND
```

```
CLS: GOSUB GRIDPRT
LOCATE 18,5: INPUT"another point to add";q$
IF q$="N" THEN q$="n"
CLS
WEND
d=d+1:xx(d)=xx(1):yy(d)=yy(1)
GOSUB SITEPRINT
LOCATE 18,5:PRINT "COMPLETED SITE"
LOCATE 18,30:PRINT "please press space bar to continue"
WHILE INKEY$<>" ":WEND
REM CHANCE TO CHANGE BOUNDARY COORDINATES
WHILE c<d:CLS
PRINT :PRINT "Opportunity to change site boundary coordinates"
PRINT :PRINT "code","x coord","y coord":
FOR a=1 TO d
PRINT a,xx(a),yy(a):NEXT a
PRINT :PRINT "enter ";d+1;" for no corrections"
PRINT :PRINT :PRINT
INPUT"enter code of coordinate you wish to change";c
INPUT"enter x coordinate (return for no change)";xx(c)
INPUT"enter y coordinate (return for no change)";yy(c)
WEND
REM ENTER OTHER SITE INFORMATION
CLS: PRINT  "INPUT ANCILLARY INFORMATION"
PRINT :INPUT"How many metres per horizontal grid";me
PRINT:INPUT"Which direction is north (0 degrees is straight up)";bear
sc=44/me
REM CALC APPROX SITE AREA
ltx=xx(1):lty=yy(1):rbx=xx(1):rby=yy(1)
```

```
FOR a = 2 TO d
IF xx(a)<ltx THEN ltx=xx(a)
IF xx(a)>rbx THEN rbx = xx(a)
IF yy(a)<lty THEN lty=yy(a)
IF yy(a)>rby THEN rby =yy(a)
NEXT
are=(rbx-ltx)*(rby-lty)*1056*(me/44)^2
PRINT :PRINT :PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
RETURN

INPUTPEOPLE:
REM PLACE WORKERS ON SITE
CLS
LOCATE 5,6:PRINT "This program allows the situation of personnel on  "
LOCATE 6,6:PRINT "site in two ways, First, you may place discrete "
LOCATE 7,6:PRINT "'clumps' of people on site, near where they actually "
LOCATE 8,6:PRINT "work.  For those with no fixed workplace, a uniform "
LOCATE 9,6:PRINT "distribution shall be assumed, over a "
LOCATE 10,6:PRINT "representative area."
PRINT :PRINT :INPUT"How many workers on site in total";tot
PRINT :INPUT "How many workers do you wish to place in discrete
positions";dtot
utot=tot-dtot:tott=0: ntot=0
PRINT :PRINT "There are ";utot; "workers to be placed uniformly on site,"
INPUT"how many of these will represent workers on site for 24hrs per day";stot
dens=(stot+(utot-stot)/4)/are:CLS
WHILE ntot<dtot
LINE(0,0)-(495,262),0,bf: GOSUB GRIDPRT
```

```
GOSUB DRAWPERS
tott=tott+1
sh(tott)=1
LOCATE 17,4:INPUT"x coord (personnel)";px(tott)
LINE (200,250)-(495,295),0,bf
LOCATE 18,4:INPUT"y coord (personnel)";py(tott)
LOCATE 17,30:INPUT"how many people";num(tott)
LOCATE 18,30:INPUT "are sites filled 24hr";q$
IF q$="N" OR q$="n" THEN sh(tott)=.25
ntot=ntot+num(tott):LINE(0,250)-(495,295),0,bf
LOCATE 18,30:PRINT "number accounted for = ";ntot
WEND
CLS: GOSUB GRIDPRT
GOSUB DRAWPERS
LOCATE 18,30:PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
RETURN

ENTERCOMP:
REM PLACE COMPARTMENTS ON SITE
CLS: PRINT :PRINT :INPUT"How many compartments";n
CLS:FOR k = 1 TO n
flag=1
WHILE flag=1
flag=0
LINE(0,0)-(495,262),0,bf
GOSUB GRIDPRT : k=k-1: GOSUB COMPTPRT: k=k+1
LOCATE 17,30:INPUT"Please enter x coord";cx(k)
LOCATE 18,30:INPUT"Please enter y coord";cy(k)
```

```
IF cx(n)>10 OR cx(n)<0 THEN flag=1
IF cy(n)>10 OR cy(n)<0 THEN flag=1
LINE (0,230)-(495,295),0,bf
IF flag=1 THEN PRINT "value outside, repeat entry"
WEND
CLS:GOSUB COMPTPRT
NEXT k
CLS: GOSUB GRIDPRT
k=n:GOSUB COMPTPRT
LOCATE 18,1:PRINT "please press space bar to continue"
WHILE INKEY$<>" ":WEND
REM ENTER COMPARTMENT PROCESS INFORMATION
FOR i=1 TO n:CLS:PRINT
PRINT "COMPARTMENT ";i
PRINT  :INPUT"Please enter name of compartment";com$(i)
PRINT :INPUT"Please enter hazard radii (in meters)";rad(i)
NEXT i
PRINT :PRINT :PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
RETURN

ENTFREQ:
REM FAILURE FREQUENCY TABLE
FOR i=1 TO n
CLS:PRINT :PRINT
PRINT "COMPARTMENT NUMBER";i;": ";com$(i):PRINT
PRINT "FREQUENCY SCALE FOR INITIATION OF INCIDENTS"
PRINT"Number","Descriptor","Numerical Value (per 100yrs)"
PRINT :FOR f=1 TO 7
```

```
PRINT f,fredis$(f),freval(f):NEXT f
PRINT
INPUT"Please enter number corresponding to chosen frequency";freq(i)
REM MITIGATION PROBABILITY TABLE
CLS:PRINT :PRINT
PRINT "COMPARTMENT NUMBER";i;": ";com$(i):PRINT
PRINT "MITIGATION PROBABILITIES OF FAILURE"
PRINT "Number","Chance of Effective Response","Probability"
PRINT :FOR p=1 TO 5
PRINT p,mitdis$(p),,mitpro(p)
NEXT p
PRINT :INPUT"Please enter number corresponding to chosen probability";x
mit(i)=x
NEXT i
PRINT :PRINT :PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
RETURN

FINAL:
REM PREPARE AND PRESENT OUTPUT DATA
CLS:PRINT "   ":PRINT "   " :PRINT "   "
GOSUB CALCINDICES: GOSUB SITEPRINT:GOSUB PRTRADII
GOSUB DIMENSION: GOSUB ARROW: GOSUB DRAWPERS
REM PRINT TO CLIPBOARD
PICTURE ON
LINE(0,0)-(0,295): LINE-(480,295):LINE-(480,0):LINE-(0,0)
PRINT " ANALYSIS RESULTS-site output"
GOSUB SITEPRINT :GOSUB PRTRADII
GOSUB DIMENSION: GOSUB ARROW: GOSUB DRAWPERS
```

```
PICTURE OFF
OPEN "clip:picture" FOR OUTPUT AS #1
PRINT #1,PICTURE$
CLOSE #1
LOCATE 18,1: PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
RETURN

GRIDPRT:
REM DRAW GRID
LINE(40,20)-(480,260),,b
FOR i= 40 TO 436 STEP 44
y=18:nu=(i-40)/44:x=i-1: GOSUB numprint
LINE (i,20)-(i,260):NEXT i
FOR i=44 TO 236 STEP 24
nu=(i-20)/24:x=36:y=i+3: GOSUB numprint
LINE(40,i)-(480,i):NEXT i
FOR a=1 TO d
LINE((xx(a)*44)+39,(yy(a)*24)+19)-((xx(a)*44)+41,(yy(a)*24)+21),,bf:NEXT a
y=18:nu=1:x=476:GOSUB numprint:nu=0:x=480:GOSUB numprint
y=262:nu=1:x=32:GOSUB numprint:nu=0:x=36:GOSUB numprint

SITEPRINT:
REM DRAW SITE BOUNDARY
PSET(xx(1)*44+40,yy(1)*24+20)
FOR a=2 TO d
LINE -((xx(a)*44)+40,(yy(a)*24)+20):NEXT a
RETURN
```

```
COMPTPRT:
REM DRAW COMPARTMENTS ON SITE
FOR i=1 TO k
LINE((cx(i)*44)+38,(cy(i)*24)+18)-((cx(i)*44)+42,(cy(i)*24)+22),,bf
NEXT i
RETURN

CALCINDICES:
REM CALCULATE INDICES AND REPORT
GOSUB EVALUATE
OPEN site$ FOR OUTPUT AS #2
siteindex=0
CLS:PRINT"HAZARD RANK ANALYSIS RESULTS":PRINT
PRINT
PRINT #2,"HAZARD RANK ANALYSIS RESULTS":PRINT#2," "
PRINT  #2, "SITE ID = ";site$:PRINT #2, " ":PRINT#2," "
PRINT  #2, "Number of people on site =";tot:PRINT #2, " "
PRINT  #2, dtot;" people are place directly on site"
PRINT  #2,utot;" people are placed uniformly on site"
PRINT  #2," "
FOR i = 1 TO n
fa(i)=freval(freq(i)):fm(i)=mitpro(mit(i))
hi(i)=pers(i)*fa(i)*fm(i)
siteindex=siteindex+hi(i)
REM PRINT TO SCREEN
PRINT :PRINT "COMPARTMENT # = ";i
PRINT "compartment type= ";com$(i)
PRINT "failure frequency = ";fa(i); " (events per 100yrs)"
PRINT "mitigation probability = ";fm(i)
```

```
PRINT "effect radii = ";rad(i);"m"
PRINT "persons affected = ";pers(i)
PRINT "hazard index = ";hi(i)
REM PRINT TO DATA FILE
PRINT #2," ":PRINT  #2,"COMPARTMENT # = ";i
PRINT #2,"compartment type= ";com$(i)
PRINT #2,"failure frequency = ";fa(i);" (events per 100yrs)"
PRINT #2,"mitigation probability = ";fm(i)
PRINT #2,"effect radii = ";rad(i);"m"
PRINT #2,"persons affected = ";pers(i)
PRINT #2,"hazard index = ";hi(i)
NEXT i
PRINT :PRINT :PRINT" SITEINDEX = "; siteindex:PRINT
PRINT#2, " " :PRINT#2, " "
PRINT #2, "SITEINDEX = "; siteindex:PRINT#2, " "
CLOSE #2
PRINT "please press space bar to continue"
WHILE INKEY$<> " ":WEND
CLS
RETURN

EVALUATE:
REM EVALUATE PEOPLE AFFECTED BY HAZARDS
FOR i=1 TO n
pers(i)=0
xdp=cx(i)*44+40:ydp=cy(i)*24+20
FOR j=1 TO tott
IF SQR(((px(j)*44+40)-xdp)^2+((py(j)*24+20)-ydp)^2)<rad(i)*sc THEN
pers(i)=pers(i)+num(j)*sh(j)
```

```
NEXT j
NEXT i
FOR i = 1 TO n
arc(i)=pi*rad(i)^2
pers(i)=pers(i)+arc(i)*dens
NEXT i
RETURN

PRTRADII:
REM DRAW EFFECT RADII
FOR l=1 TO n
LINE((cx(l)*44)+38,(cy(l)*24)+18)-((cx(l)*44)+42,(cy(l)*24)+22),,bf
CIRCLE(cx(l)*44+40,cy(l)*24+20),rad(l)*sc
xhs=cx(l)*44 +34
yhs=cy(l)*24+29
LINE(xhs,yhs)-(xhs+9,yhs-6),0,bf
LINE (xhs+1,yhs)-(xhs+1, yhs-4)
LINE (xhs+3,yhs)-(xhs+3, yhs-4)
LINE (xhs,yhs-1)-(xhs+4, yhs-1)
LINE (xhs,yhs-3)-(xhs+4, yhs-3)
x=xhs+6:y=yhs:nu=l
GOSUB numprint
NEXT l
RETURN

DRAWPERS:
REM DRAW PERSONS ON SITE
FOR i=1 TO tott
nu=num(i):x=px(i)*44+39:y=py(i)*24+23
```

```
LINE(x-2,y+3)-(x+6,y-7),0,bf
IF nu<10 THEN GOSUB numprint
IF nu>=10 THEN nux=nu:nu=INT(nu/10):GOSUB numprint:x=x+5:nu=nux-
nu*10:GOSUB numprint
NEXT i
RETURN

DIMENSION:
REM DRAW SCALE ON SITE
r=20*sc
xr=5:yr=150
LINE(xr,yr-4)-(xr,yr)
LINE -(xr+r,yr) : LINE -(xr+r,yr-4)
LINE(xr+r/2,yr)-(xr+r/2,yr-4)
x=xr-1:y=yr-6:nu=0: GOSUB numprint
x=xr+r/2+1: GOSUB numprint
x=xr+r+1: GOSUB numprint
nu=1:x=xr+r/2-4: GOSUB numprint
nu=2:x=xr+r-4: GOSUB numprint
ym=yr-6:xm=xr+r+8
LINE(xm, ym-1)-(xm,ym-4)
LINE(xm+2,ym-1)-(xm+2,ym-4)
LINE(xm+8,ym-1)-(xm+8,ym-4)
LINE(xm+4,ym-1)-(xm+4,ym-3)
LINE(xm+6,ym-1)-(xm+6,ym-3)
PSET(xm+1,ym): PSET(xm+7,ym): PSET(xm+1,ym-5)
PSET(xm+7,ym-5): PSET(xm+3,ym-3):PSET(xm+5,ym-3)
RETURN
```

```
ARROW:
REM DRAW BEARING ON SITE
xa=28:ya=100
thet=bear/57.29
xh=20*SIN(thet):yh=20*COS(thet)
LINE (xa,ya)-(xa+xh,ya-yh)
xn=xa+1.3*xh: yn=ya-1.3*yh
REM PRINT ARROW HEAD
xal=3*SIN(thet+.785): yal=3*COS(thet+.785)
xar=3*SIN(thet-.785): yar=3*COS(thet-.785)
LINE(xa+xh-xar,ya-yh+yar)-(xa+xh,ya-yh)
LINE -(xa+xh-xal,ya-yh+yal)
REM PRINT "N" FOR NORTH
PSET(xn,yn): PSET(xn,yn-1): PSET(xn,yn-2): PSET(xn,yn-3): PSET(xn,yn-4)
PSET(xn+3,yn): PSET(xn+3,yn-1): PSET(xn+3,yn-2): PSET(xn+3,yn-3)
PSET(xn+3,yn-4): PSET(xn+1,yn-3):PSET(xn+2,yn-2)
RETURN

numprint:
REM DRAW SMALL NUMBERS ON SITE
SELECT CASE nu
CASE 0
PSET(x,y ):PSET(x+1,y): PSET (x+2,y)
PSET(x,y-1):PSET(x,y-2): PSET(x,y-3)
PSET(x,y-4):PSET(x,y-5):PSET(x+2,y-5): PSET(x+1,y-5)
PSET(x+2,y-4): PSET(x+2,y-3): PSET(x+2,y-2):PSET (x+2,y-1)
CASE 1
PSET(x,y):PSET(x+1,y):PSET(x+2,y)
PSET(x+1,y-1):PSET(x+1,y-2):PSET(x+1,y-3)
```

```
PSET(x+1,y-4):PSET(x+1,y-5):PSET(x,y-4)
CASE 2
PSET(x,y):PSET(x+1,y):PSET(x+2,y)
PSET(x,y-1):PSET(x+1,y-2):PSET(x+2,y-3)
PSET(x+2,y-4):PSET(x+1,y-5):PSET(x,y-4)
CASE 3
PSET(x,y):PSET(x+1,y)
PSET(x+2,y-1):PSET(x+2,y-2):PSET(x+2,y-3)
PSET(x+2,y-4):PSET(x+1,y-3):PSET(x+1,y-5): PSET(x,y-5)
CASE 4
PSET(x+2,y-5):PSET(x+2,y-4):PSET(x+2,y-3):PSET(x+2,y-2)
PSET(x+2,y-1):PSET(x+2,y):PSET(x+1,y-2):PSET(x,y-2)
PSET(x,y-3):PSET(x+1,y-4)
CASE 5
PSET(x,y-1):PSET(x+1,y)
PSET(x+2,y-1):PSET(x+2,y-2):PSET(x+2,y-3)
PSET(x+1,y-3):PSET(x,y-3):PSET(x,y-4): PSET(x,y-5)
PSET(x+1,y-5): PSET(x+2,y-5)
CASE 6
PSET(x,y ):PSET(x+1,y): PSET (x+2,y)
PSET(x,y-1):PSET(x,y-2): PSET(x,y-3): PSET (x+1,y-2)
PSET(x,y-4):PSET(x,y-5):PSET(x+2,y-5): PSET(x+1,y-5)
PSET(x+2,y-4):PSET(x+2,y-2):PSET (x+2,y-1)
CASE 7
PSET(x+1,y): PSET(x+1,y-1):PSET(x,y-5):PSET(x+1,y-5):PSET(x+2,y-5)
PSET(x+2,y-4):PSET(x+2,y-3):PSET(x+1,y-3):PSET(x+1,y-2)
CASE 8
PSET(x,y ):PSET(x+1,y): PSET (x+2,y)
PSET(x,y-1):PSET(x,y-2): PSET(x,y-3): PSET (x+1,y-3)
```

```
PSET(x,y-4):PSET(x,y-5):PSET(x+2,y-5): PSET(x+1,y-5)
PSET(x+2,y-4): PSET(x+2,y-3): PSET(x+2,y-2):PSET (x+2,y-1)
CASE 9
PSET(x,y-1):PSET(x+1,y): PSET (x+2,y-4)
PSET(x+2,y-1):PSET(x+2,y-2): PSET(x+2,y-3)
PSET(x+1,y-3):PSET(x,y-3):PSET(x,y-4): PSET(x,y-5)
PSET(x+1,y-5): PSET(x+2,y-5): PSET(x,y): PSET(x+2,y)
CASE ELSE
LINE(200,280)-(202,282),,bf
END SELECT
RETURN

REM DATA FILES
DATA Very Often ,1000,Often ,100
DATA Likely,10,Possible,1,Unlikely,0.1,Very Unlikely,0.01
DATA Barely Credible,0.001
DATA Negligible,1,Low,0.8,Fair,0.5
DATA Good,0.2,Excellent,0
```

Appendix 3. Variable explanations

Variable / String	Explanation
a	loop variable in SITEPRINT
arc()	area covered by effect of each compartment
are	area of over which uniform personnel density is calculated
bear	input of bearing (in degrees)
c	coordinate change variable in ENTERSITE
com$()	name of compartment
cx(), cy()	coordinates of compartments
d	number of sides to site boundary
dens	uniform personnel density
dtot	number of personnel to be placed in discrete positions on site
f	associated code for failure frequency table
fa()	frequency of failure for component
flag	flag variable to validate input data in ENTERSITE and ENTERCOMP
fm()	mitigation probability for component
fredis$()	array for frequency descriptors
freq()	frequency number for compartment
freval()	array for frequency values
hi()	hazard index for compartment
i	generic variable for loops throughout software
j	loop variable in EVALUATE
k	loop variable in ENTERCOMP
l	loop variable for PRTRADII
ltx, lty	top left x and y coordinates of area used for calculating uniform personnel density
me	meters per horizontal grid
mit()	mitigation number for compartment
mitdis$()	mitigation descriptor string
mitpro()	mitigation probability string
n	number of compartments
ntot	number of workers accounted for so far in input process
nu	case number for NUMPRINT
num()	number of people at a certain personnel site
nux	variable in DRAWPERS for second digit in agglomerations of more than 10 people
p	association code for mitigation probability table
pers()	persons affected by hazards from compartment
pi	constant of π (= 3.1416)
px(), py()	coordinates for personnel locations
q$	generic question string
r	pixel length of 20m in DIMENSION
rad()	effect radii for each compartment

rbx, rby	bottom right x and y coordinates of area used for calculating uniform density
sc	scale, pixels per meter
sh()	the multiplier differentiating between day and shift work
site$	name of site
siteindex	hazard index summation variable for entire site for all hi(i)
stot	the number of uniformly distributed people in 24hr jobs
thet	bearing (converted to radians)
tot	total number of workers on site
tott	number of personnel locations
utot	number of personnel to be uniformly placed on site
x, y	coordinates for the NUMPRINT routine, placing small numbers.
xa, ya	coordinates for base of ARROW
xal, yal	left tip of ARROW
xar, yar	right tip of ARROW
xdp, ydp	pixel derivative for grid coordinates of compartments
xh, yh	coordinates for ARROW head
xhs, yhs	coordinates for compartment identifier
xm, ym	coordinates of (m) in DIMENSION
xn, yn	coordinates for letter N in ARROW
xr, yr	coordinates for scale in DIMENSION
xx(), yy()	site boundary coordinates

Appendix 4. Subroutine Explanations

SUBROUTINE NAME	EXPLANATION
ARROW	ARROW draws an arrow showing the direction of North. The angle of the arrow is entered in ENTERSITE. and is only shown in the final report printout.
CALCINDICES	This routine groups data and calculates hazard indices for each compartment. It is controlled by FINAL routine.
COMPTPRT	COMPTPRT draws small filled black squares where the compartments are on site.
DIMENSION	After entry of distance per horizontal grid length in ENTERSITE, this routine prints out a scale for the final report showing how long 20 meters is.
DRAWPERS	Draws the situation of personnel agglomerations on site, along with the number at each coordinate.
ENTERCOMP	Enters the coordinates of process compartments onto the site and grid.
ENTERSITE	This routine accepts data for the shape of the site boundary. Data is entered onto a 10x10 grid.
ENTFREQ	This routine presents tables showing failure frequency and mitigation probability choices. These choices form two of the indices that comprise the hazard index.
EVALUATE	Evaluates the numbers of people affected by each compartment hazard.
FINAL	FINAL prepares the summary output data, coordinates output to the screen, clipboard (for diagrams) and to an output data file (for report information summary).
GRIDPRT	Draws the 10 x 10 grid upon which site data is entered. Small numbers for grid entry are taken from NUMPRINT.
INPUTPEOPLE	Inputs the coordinated for the discrete positioning of personnel onto the site.
NUMPRINT	This is a generic routine that prints small numbers on screen at required coordinates.
PRTRADII	This routine draws effect radii around the compartment coordinates.
SITEPRINT	SITEPRINT is tacked onto the end of GRIDPRT to print out just the site boundary, when required.
START	This routine initialises variables, shows title box and reads relevant data from files at the end of the code.

Appendix 5. Full Output from Hazrank Software

example 1

HAZARD RANK ANALYSIS RESULTS

SITE ID = sulphuric acid productions

Number of people on site = 25

18 people are place directly on site
7 people are placed uniformly on site

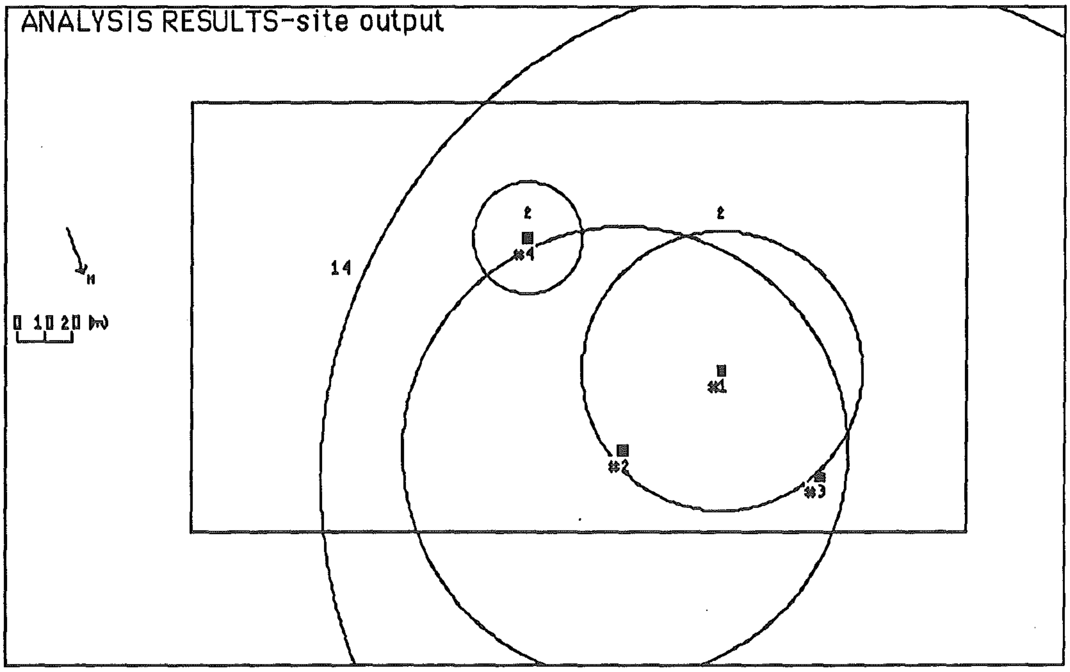
COMPARTMENT # = 1
compartment type= sulphur melter
failure frequency = 10 (events per 100yrs)
mitigation probability = .5
effect radii = 50 m
persons affected = 1.010134
hazard index = 5.050669

COMPARTMENT # = 2
compartment type= sulphur burner
failure frequency = .1 (events per 100yrs)
mitigation probability = .5
effect radii = 80 m
persons affected = 2.585943
hazard index = .1292971

COMPARTMENT # = 3
compartment type= LPG bullet
failure frequency = .01 (events per 100yrs)
mitigation probability = .2
effect radii = 180 m
persons affected = 15.59134
hazard index = 3.118267E-02

COMPARTMENT # = 4
compartment type= acid storage
failure frequency = 100 (events per 100yrs)
mitigation probability = .2
effect radii = 20 m
persons affected = .6616214
hazard index = 13.23243

SITEINDEX = 18.44358



Appendix 5.

example 2

HAZARD RANK ANALYSIS RESULTS

SITE ID = sulphuric acid productions 2

Number of people on site = 25

18 people are place directly on site
7 people are placed uniformly on site

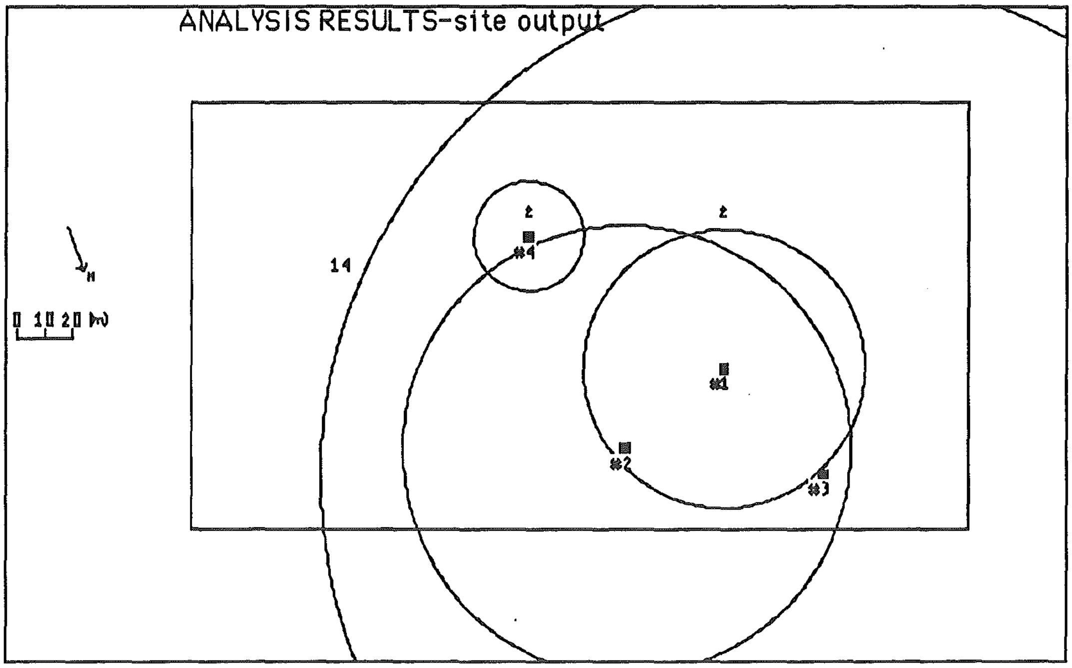
COMPARTMENT # = 1
compartment type= sulphur melter
failure frequency = 10 (events per 100yrs)
mitigation probability = .5
effect radii = 50 m
persons affected = 1.010134
hazard index = 5.050669

COMPARTMENT # = 2
compartment type= sulphur burner
failure frequency = .1 (events per 100yrs)
mitigation probability = .5
effect radii = 80 m
persons affected = 2.585943
hazard index = .1292971

COMPARTMENT # = 3
compartment type= LPG bullet
failure frequency = .01 (events per 100yrs)
mitigation probability = .2
effect radii = 180 m
persons affected = 15.59133
hazard index = 3.118267E-02

COMPARTMENT # = 4
compartment type= acid storage
failure frequency = 1 (events per 100yrs)
mitigation probability = .2
effect radii = 20 m
persons affected = .6616214
hazard index = .1323243

SITEINDEX = 5.343473



Appendix 5.

example 3

HAZARD RANK ANALYSIS RESULTS

SITE ID = sulphuric acid productions 3

Number of people on site = 25

18 people are place directly on site
7 people are placed uniformly on site

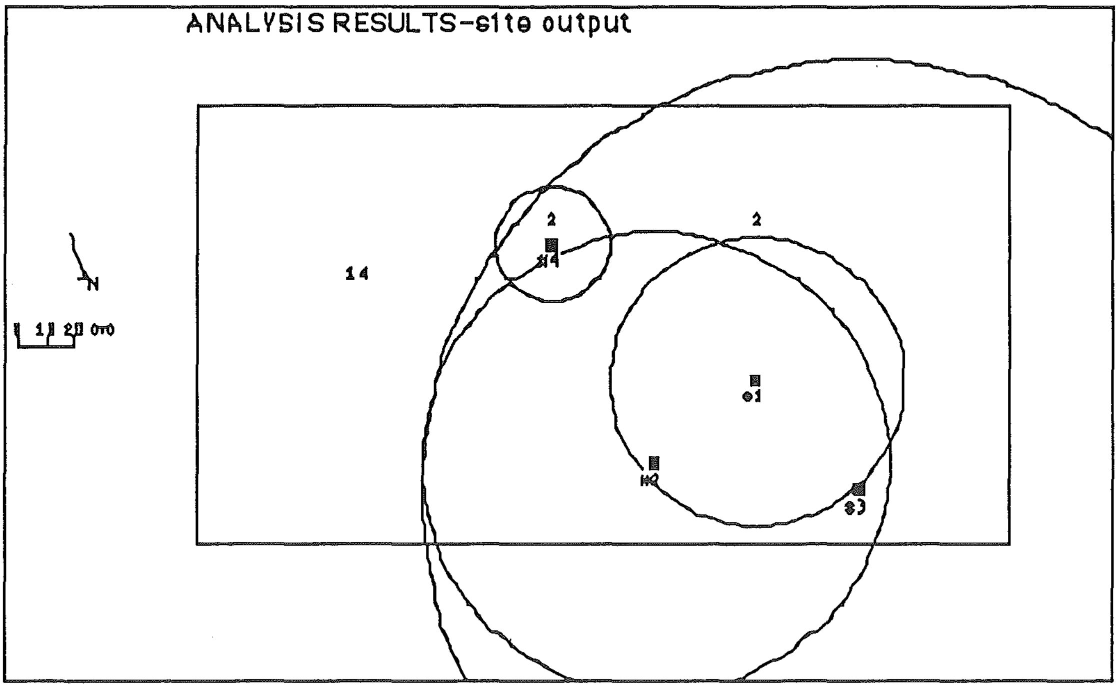
COMPARTMENT # = 1
compartment type= sulphur melter
failure frequency = 1 (events per 100yrs)
mitigation probability = .5
effect radii = 50 m
persons affected = 1.010134
hazard index = .5050669

COMPARTMENT # = 2
compartment type= sulphur burner
failure frequency = .1 (events per 100yrs)
mitigation probability = .5
effect radii = 80 m
persons affected = 2.585943
hazard index = .1292971

COMPARTMENT # = 3
compartment type= LPG bullet
failure frequency = .01 (events per 100yrs)
mitigation probability = .2
effect radii = 150 m
persons affected = 11.59121
hazard index = 2.318241E-02

COMPARTMENT # = 4
compartment type= acid storage
failure frequency = 100 (events per 100yrs)
mitigation probability = .2
effect radii = 20 m
persons affected = .6616214
hazard index = 13.23243

SITEINDEX = 13.88997



Appendix 5.

example 4

HAZARD RANK ANALYSIS RESULTS

SITE ID = sulphuric acid productions 4

Number of people on site = 25

18 people are place directly on site
7 people are placed uniformly on site

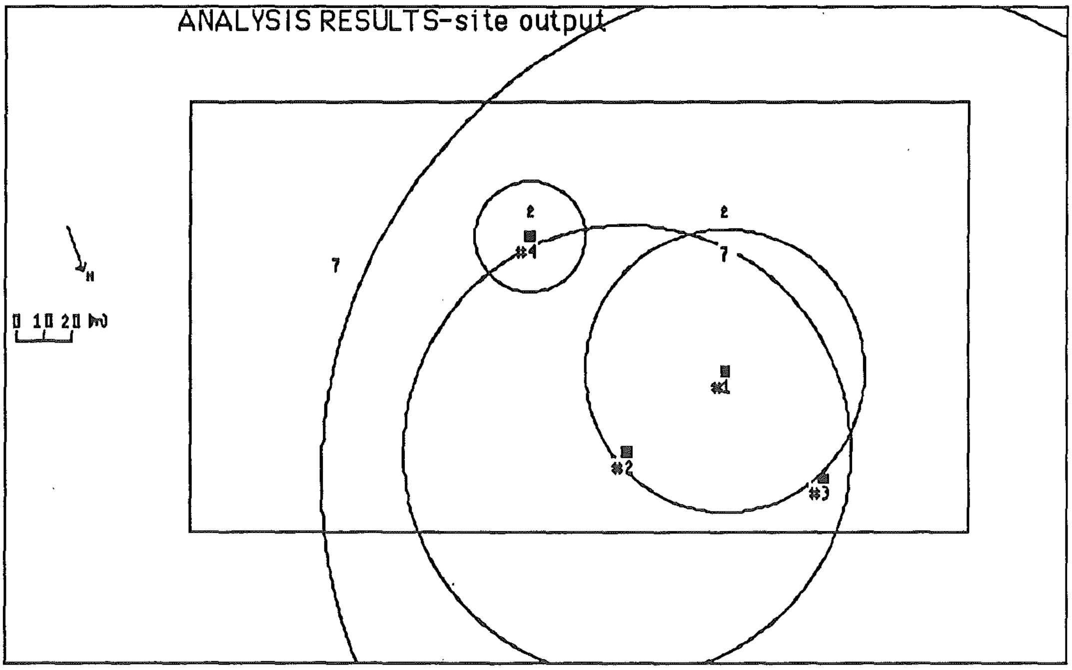
COMPARTMENT # = 1
compartment type= sulphur melter
failure frequency = 10 (events per 100yrs)
mitigation probability = .5
effect radii = 50 m
persons affected = 2.760134
hazard index = 13.80067

COMPARTMENT # = 2
compartment type= sulphur burner
failure frequency = .1 (events per 100yrs)
mitigation probability = .5
effect radii = 80 m
persons affected = 4.335942
hazard index = .2167971

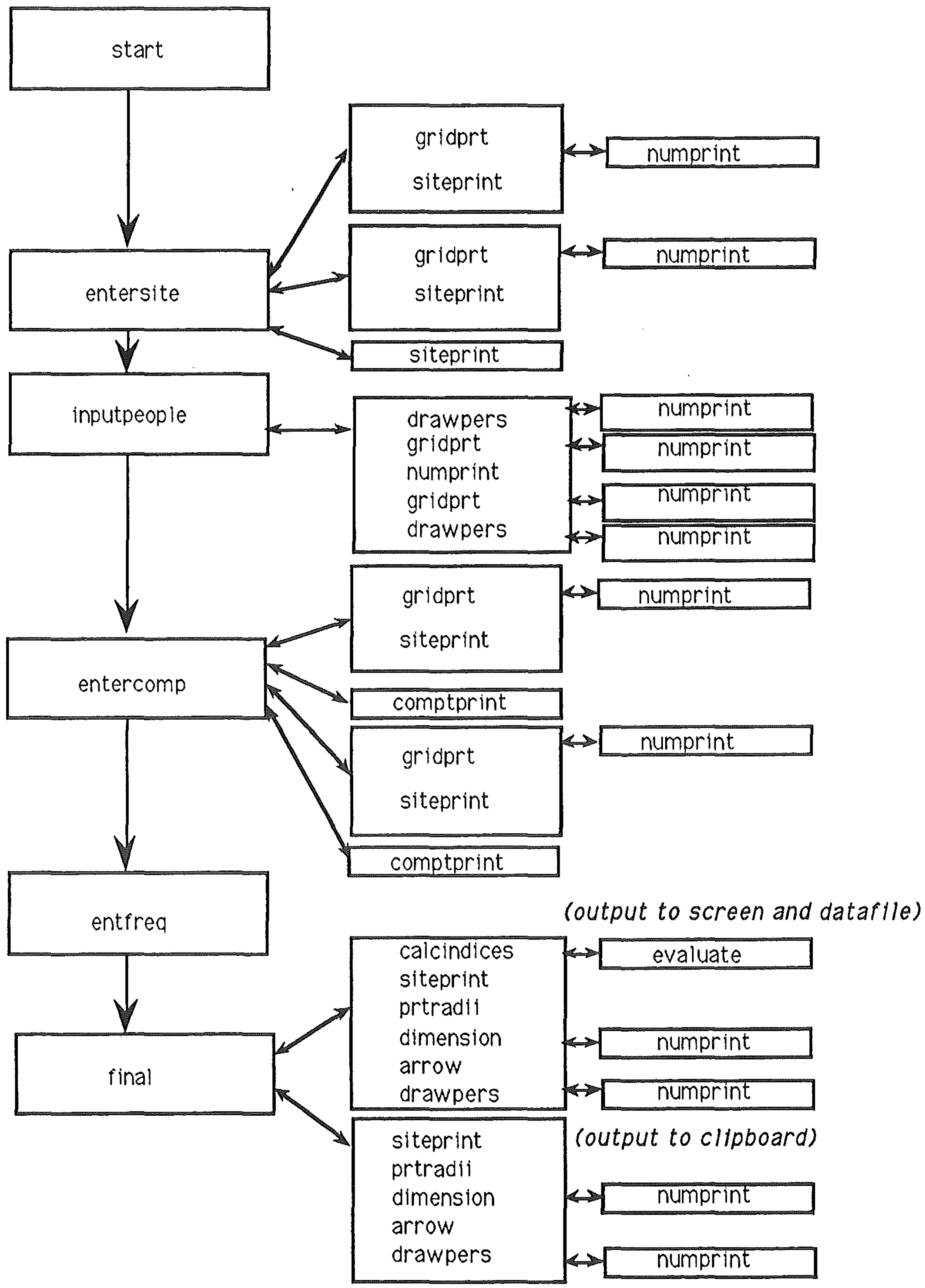
COMPARTMENT # = 3
compartment type= LPG bullet
failure frequency = .01 (events per 100yrs)
mitigation probability = .5
effect radii = 180 m
persons affected = 17.34134
hazard index = 8.670668E-02

COMPARTMENT # = 4
compartment type= acid storage
failure frequency = 100 (events per 100yrs)
mitigation probability = .2
effect radii = 20 m
persons affected = .6616214
hazard index = 13.23243

SITEINDEX = 27.3366



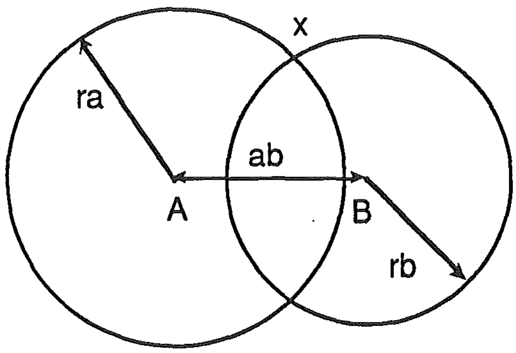
Appendix 6. Interaction of Subroutines



Appendix 7. Proof of calculation of area of overlap between two circles

Consider two circles A and B in Figure 1. The radius of A is ra, the radius of B is rb. The point at x denotes the top intersection of the two circles.

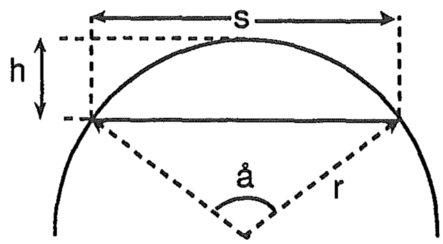
Figure A7.1



The the area of overlap is calculated by adding the areas of the two segments within the overlaps.

Gieck (1985) gives the diagram in Figure A7.2 and equation (1) for the calculation of a segment of a circle;

Figure A7.2



$$A_{segment} = \frac{h}{6s}(3h^2 + 4s^2) \qquad (1)$$

A simplification of the geometry in Figure A7.1 can be seen in Figure A7.3;

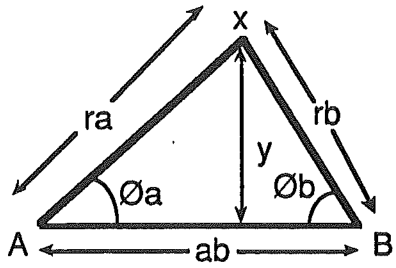


Figure A7.3

From basic trigonometry;

$$y = ra.\mathrm{Sin}\varnothing a = rb.\mathrm{Sin}\varnothing b \qquad (2)$$

and

$$ab = ra.\mathrm{Cos}\varnothing a + rb.\mathrm{Cos}\varnothing b \qquad (3)$$

The solving of equations (2) and (3) simultaneously will give values for Øa and Øb. The method for calculation is in the program Theta.

Equating Figures A7.2 and A7.3;

$$s = 2.y = 2.ra.\mathrm{Sin}\varnothing a \text{ (or } 2.rb.\mathrm{Sin}\ \varnothing b), (å = 2.\varnothing) \qquad (4)$$

$$h = r - r.\ \cos\varnothing = r(1-\mathrm{Cos}\varnothing) \qquad (5)$$

(ha and hb calculated for both Øa and Øb)

Therefore the areas of the segments can each be calculated using equation (1). Software has been written to calculate the overlap area. A description can be found in Appendix 8 and a listing in Appendix 9

Rules of overlap

When writing computer software to perform a task, it is important that the software is able to recognise all cases and able to use the appropriate method to complete the task. This means that rules must be described for all cases. Detailed below are rules for the calculation of the overlap area between two circles.

Consider the overlap of two circles in Figure A7.4, A and B.

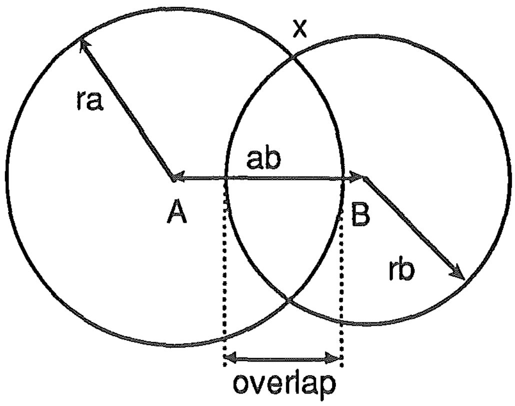


Figure A7.4

The basis for this analysis is that ra ≥ rb

overlap = ra + rb - ab

rule 1

if overlap ≤ 0 then no overlap

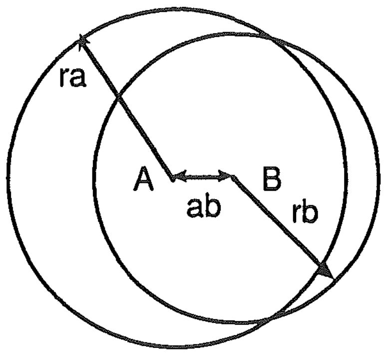
rule 2

if ab ≤ ra-rb then circle B is totally within circle A and Area overlap = πrb^2

rule 3

There is a change to the technique if Øb>90°, i.e. in the case of Figure A7.5;

Figure A7.5



The central triangle in the middle of the overlap area looks like Figure A7.6;

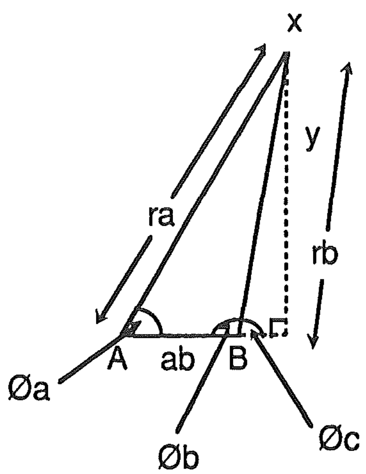


Figure A7.6

The basic equations used in the method to calculate overlap areas were;

$$y = ra.\text{Sin}Øa \qquad (1)$$

and $y = rb.Sin Øb$ (1a)

From the diagram, it looks as if the equation should read;

$y = rb.SinØc$ (1b)

$Øc = 180-Øb$ and since $SinØ = Sin(180-Ø)$ for all Ø, equations (1) and (1a) remain an accurate representation of the geometry.

The second equation used was;

$ab = ra.CosØa + rb.CosØb$ (3)

In this case (ra.CosØa) is larger than (ab), but (rb.CosØb) will be negative. Since $CosØ = -(Cos(180-Ø))$ for all Ø, the triangle described by the points x and B and the line y in Figure 6 can be mirrored in the line y. This means that the result for (rb.CosØb) will be equal to (ab-ra.CosØa). Thus equation (4) also remains an accurate representation of the geometry. With both equations (1) and (3) remaining true to the situation the method discussed is appropriate for all situations.

The only change for cases where $Øb>90°$ will be that the segment off concern will be on the other side of the circle's centre point.

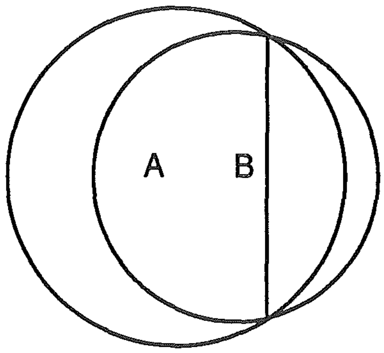


Figure A7.7

Instead of the overlap area being sum of the two segments defined (See Figure A7.7), the overlap area will be the area of the segment calculated by the area of the A circle plus (the total area of the B circle, minus the area defined in the segment calculation).

Appendix 8. Software to calculate areas of overlap.

Theta is the software written to calculate the area of overlap between two circles.

The software first requests the entry of the radii of the two circles in question and the distance between their centres. If the software were absorbed into the main hazard analysis software, the radii would be input from the effect radii calculated in the Whazan II software. The distance between their centres can be calculated from the co-ordinates at those points.

This information is then taken into the iteration routine. The routine uses a loop to estimate a series of values for Øb and applies equation (1) to calculate Øa. Using both of Øa and Øb, an estimate of the length between the circle centres (ab) is calculated using equation (3). When the difference between the calculated values for ab and the input value changes sign, the iteration routine trips back to the main program. In the main program the difference between the calculated and estimated ab value are compared to an acceptable value (in this software, 0.1). If the difference between the two values is acceptable, the routine that calculates the area of overlap is called up, the results are printed to the screen and the software execution ends. If the difference is unacceptable, the increment used for iterating is reduced, the range of values for iteration is more closely defined around the point where the sign was changed. the iteration routine is the invoked again.

There is a routine in the theta software called ARCSIN. It calculates the inverse sine of a value. It was necessary to write because the Microsoft Quickbasic software has no set function for inverse trigonometric functions. In the routine, a loop checks degree values between 0° and 90° in increments of 0.05 against the actual sine values until they are correct within an error of 0.001.

Theta would be utilised in a separate program. This is because the iteration procedures make execution of an overlap analysis a long process (4-10 minutes for systems with four effect radii). The Hazard Ranking software would download all relevant data (compartment co-ordinates, radii, frequencies, probabilities and personnel locations) into a data file, which this software would then retrieve. The software would compare all radii with each other, two at a time. The larger radius would be assigned the A value.

Appendix 9. Software listing - Theta printout

```
DIM x(100), s(100)
pi=3.1416
da=0:db=180:dc=10:delx=0
del=200

INPUT"please enter radius of A";ra
INPUT"please enter radius of B";rb
INPUT"please enter distance between A and B";ab

WHILE del>.1
GOSUB iter
da=delx-dc:db=delx+dc:dc=dc/10
WEND

GOSUB fin

REM CALCULATION OF OVERLAP AREA
haa=ra-ra*COS(theta)
hbb=rb-rb*COS(thetb)
s=2*ra*SIN(theta)
aaa=(haa/(6*s))*(3*haa^2+4*s^2)
abb=(hbb/(6*s))*(3*hbb^2+4*s^2)
att=aaa+abb
PRINT :PRINT "Area A = ";pi*ra^2
PRINT "Area B = ";pi*rb^2
PRINT "Area of Intersection = ";att
PRINT "please press space bar to continue"
```

```
WHILE INKEY$<> " ":WEND
END

iter:
REM ITERATION TO FIND THETA AND THETB
c=2:s(1)=0: flag = 0: n=0
FOR p = da TO db STEP dc
thetb=p*pi/180
si=(rb/ra)*SIN(thetb)
GOSUB arcsin
x(c)=ra*COS(theta)+rb*COS(thetb)

n=x(c)-ab
IF n>0 THEN s(c)=2 ELSE s(c)=1
IF s(c)=2 AND s(c-1)=1 THEN flag=1
IF s(c)=1 AND s(c-1)=2 THEN flag = 1
PRINT p,x(c)

IF flag=1 THEN delx=p: del =ABS(x(c)-ab): RETURN



c=c+1
NEXT
RETURN

fin:
REM PRINT OUT THETA AND THETB
PRINT :PRINT "thetb = ";delx
si=(rb/ra)*SIN(delx*pi/180)
```

```
GOSUB arcsin
PRINT "theta = ";theta*180/pi
RETURN


arcsin:
REM ARCSINE ESTIMATION
FOR i=0  TO 90 STEP .05
j=i*pi/180
IF ABS(si-SIN(j))<.001 THEN theta=i
NEXT i
theta=theta*pi/180
RETURN
```

Appendix 10. Flow Diagrams For Encoding Fault Tree Operations

Figure A10.1. Procedure For Calculating Probability Of An Ineffective Response For Several Mitigation Devices

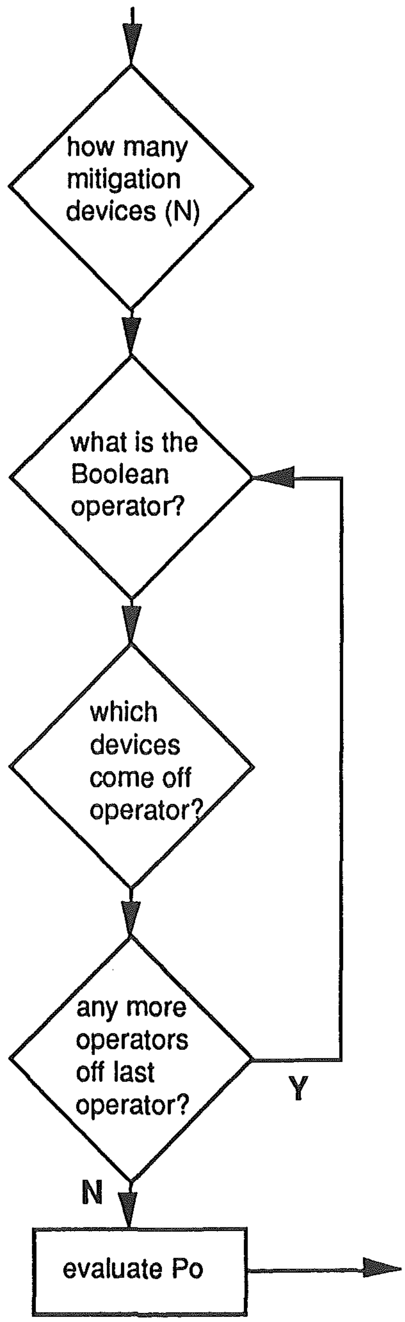
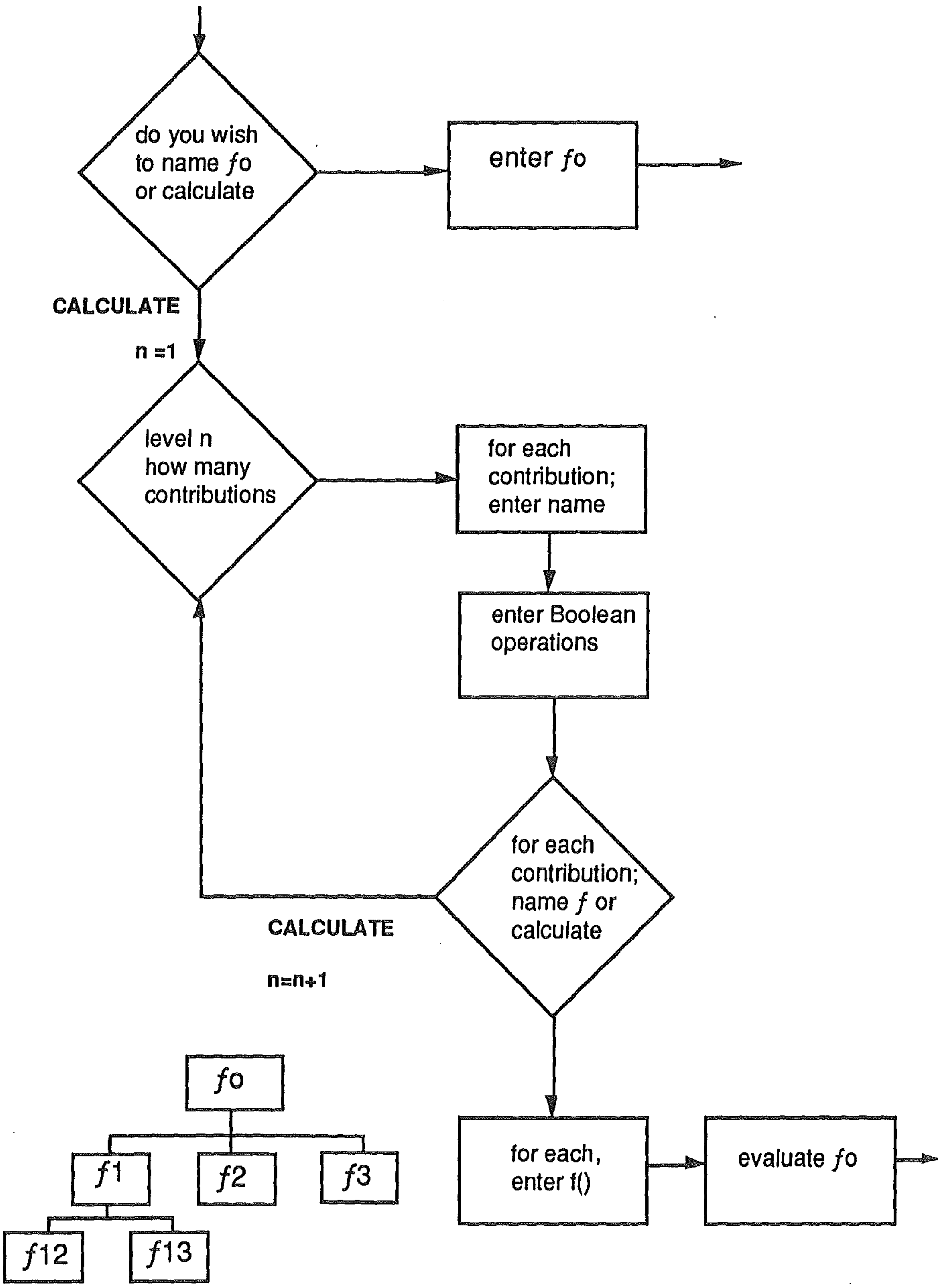


Figure A10.2. Procedure For Calculation Of Frequency Of Failure For Several Contributing Factors

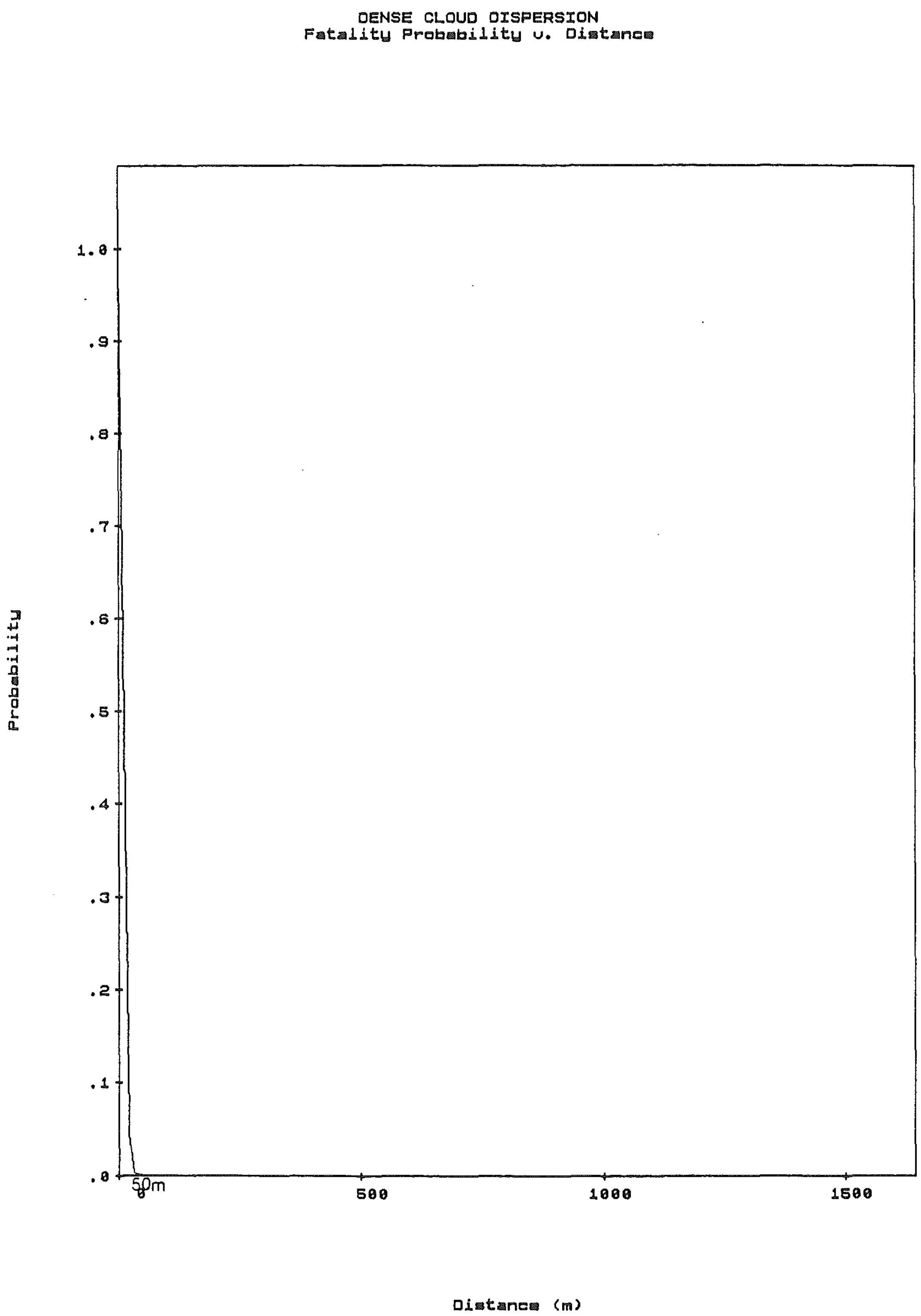


Appendix 11. Whazan II Results

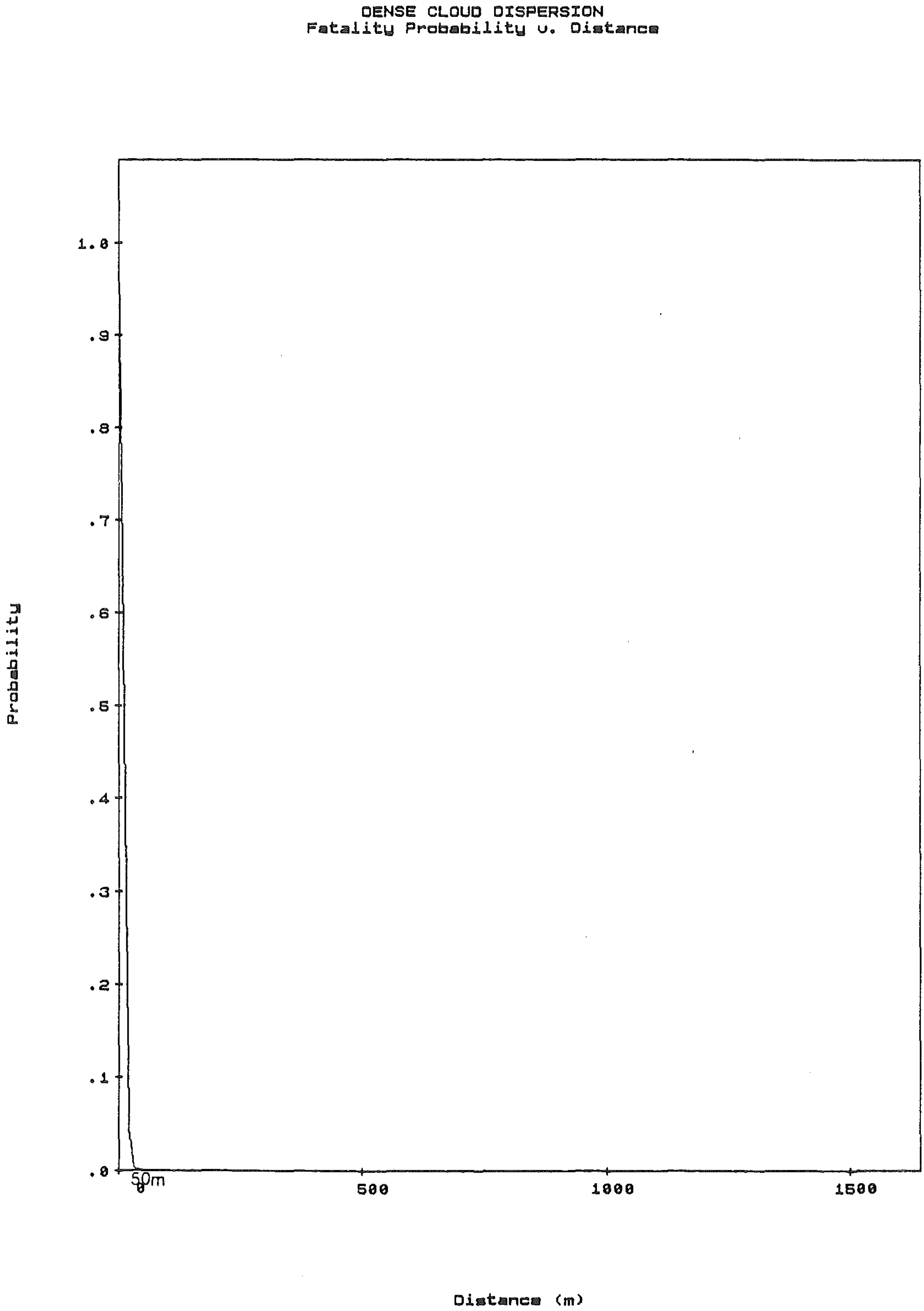
Dense Cloud Dispersion

MATERIAL	**Sul. Dioxide**
INPUT DATA	
Effective release height (m)	5.000
Release rate (kg/s)	1
Release duration (s)	120.0
Dilution factor	2
Wind speed (m/s)	3.000
Ambient temperature (K)	293
Surface roughness factor	0.2000
Atmospheric stability (A-F)	D
Min conc of interest (vol %)	5.000 E-4
RESULTS	
Max downwind effect distance (m)	1590
Max Toxic Effect (fatality prob)	1

Appendix 11 Whazan Results Sulphur Dioxide



Appendix 11 Whazan Results Sulphur Dioxide



Dense Cloud Dispersion

MATERIAL	**Hy. Sulphide**

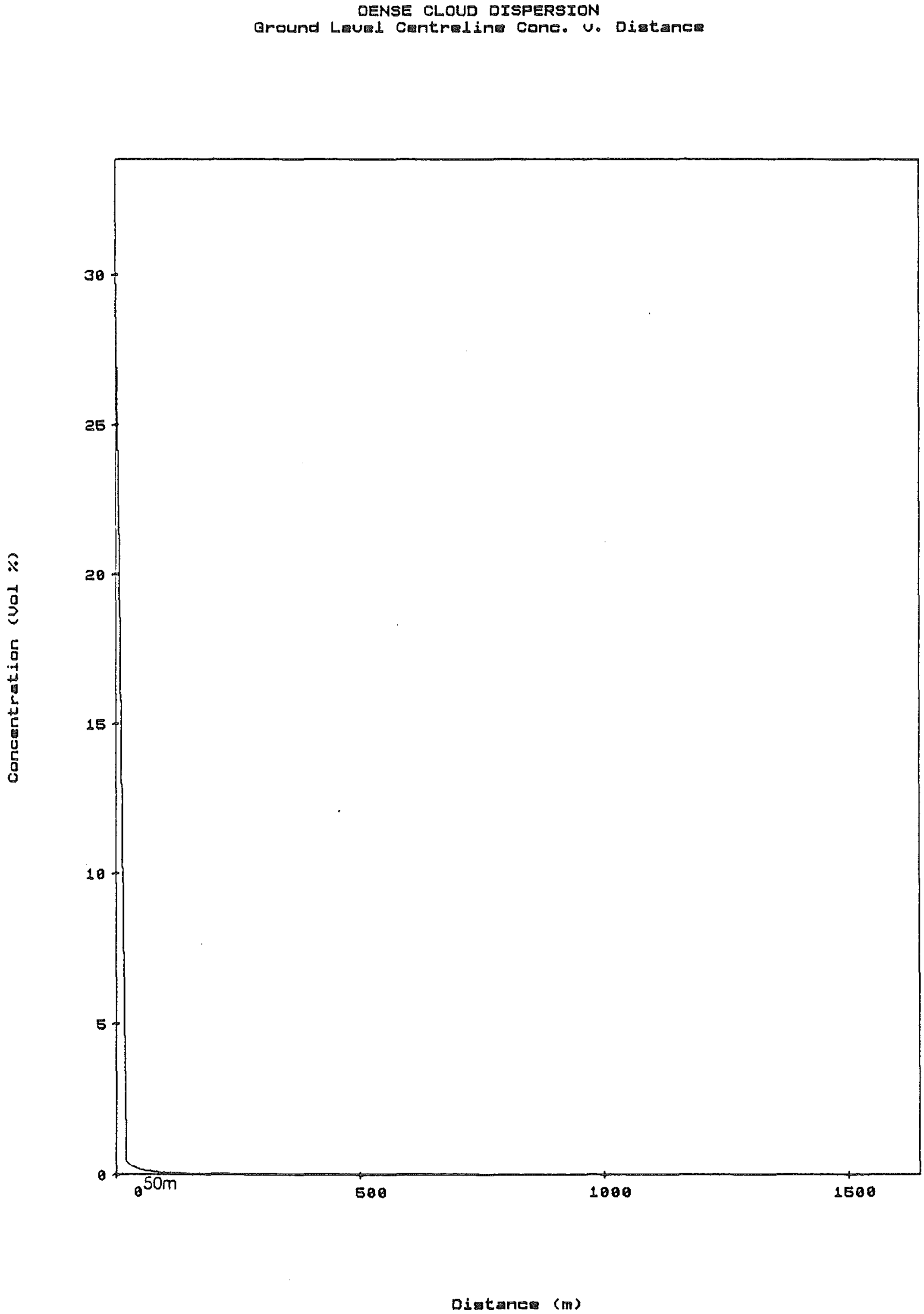
INPUT DATA

Effective release height (m)	5.000
Mass released (kg)	1.000
Dilution factor	10
Wind speed (m/s)	3.000
Ambient temperature (K)	325
Surface roughness factor	0.2000
Atmospheric stability (A-F)	D
Min conc of interest (vol %)	1.5000 E-3

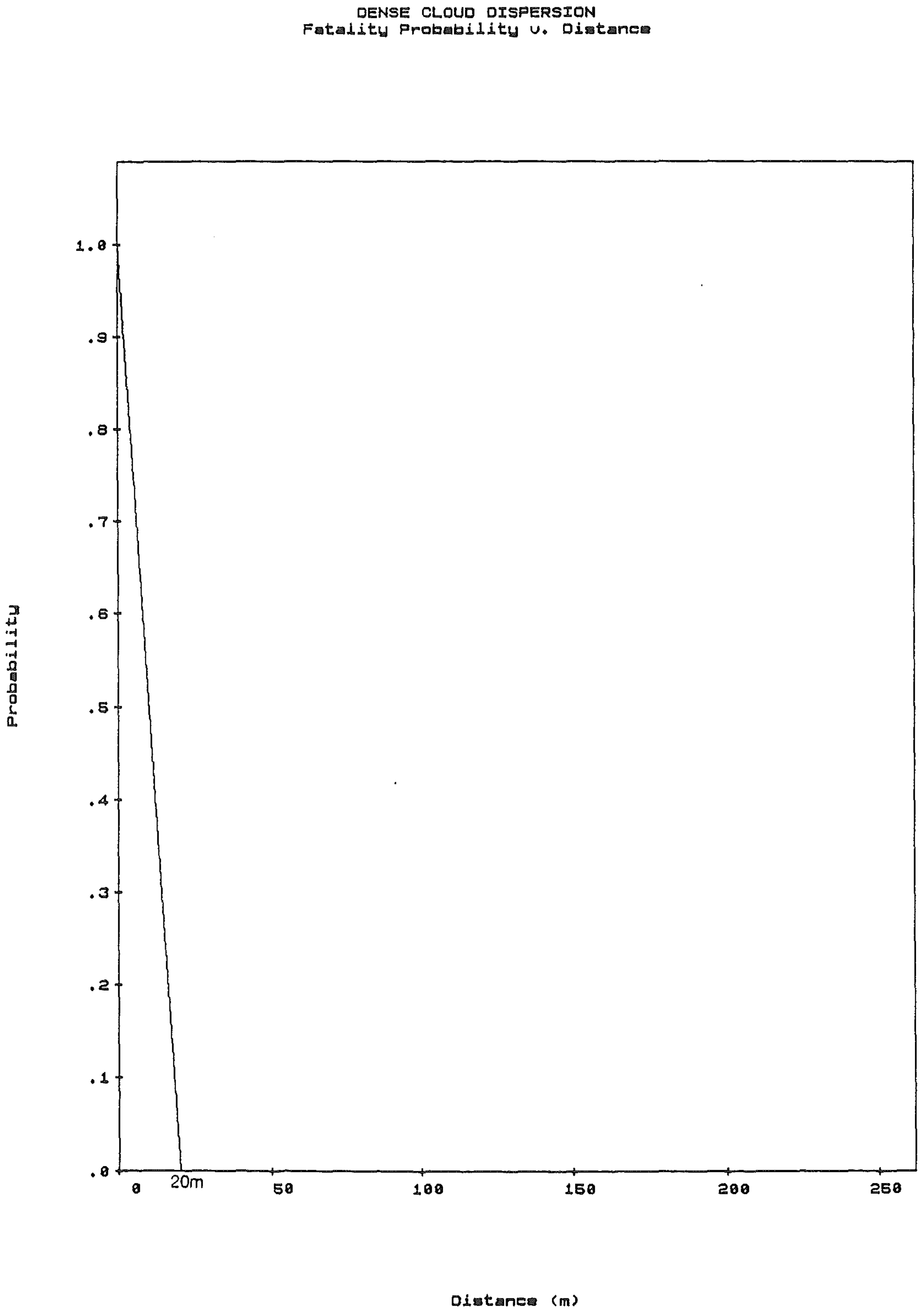
RESULTS

Max downwind effect distance (m)	240
Max Toxic Effect (fatality prob)	0.9998

Appendix 11 Whazan Results Hydrogen Sulphide



Appendix 11/ Whazan Results Hydrogen Sulphide



Fireball/ Bleve Model

Material	**Propane**

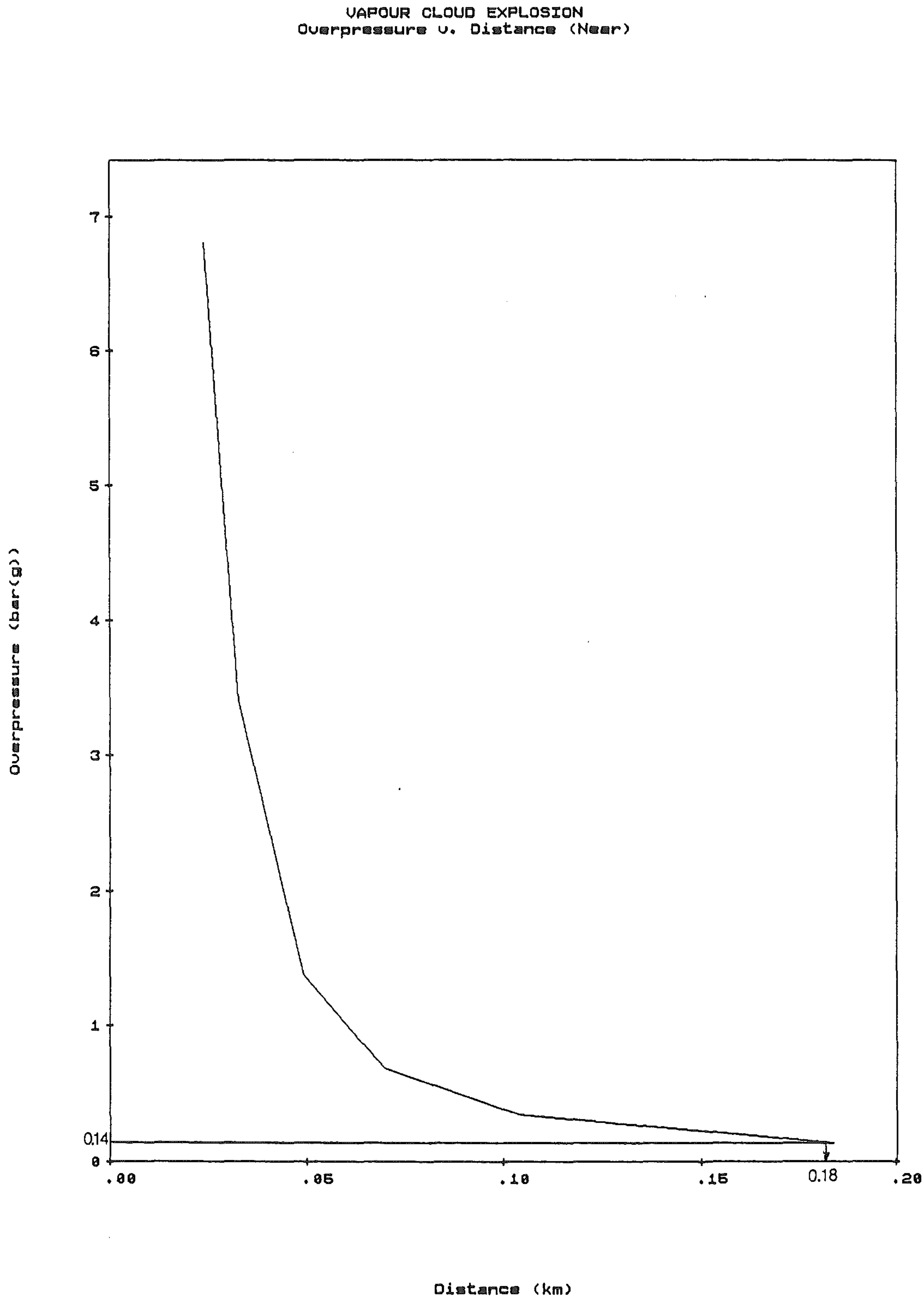
INPUT DATA

Flammable Mass (kg)	1666
Efficiency Factor	0.2000

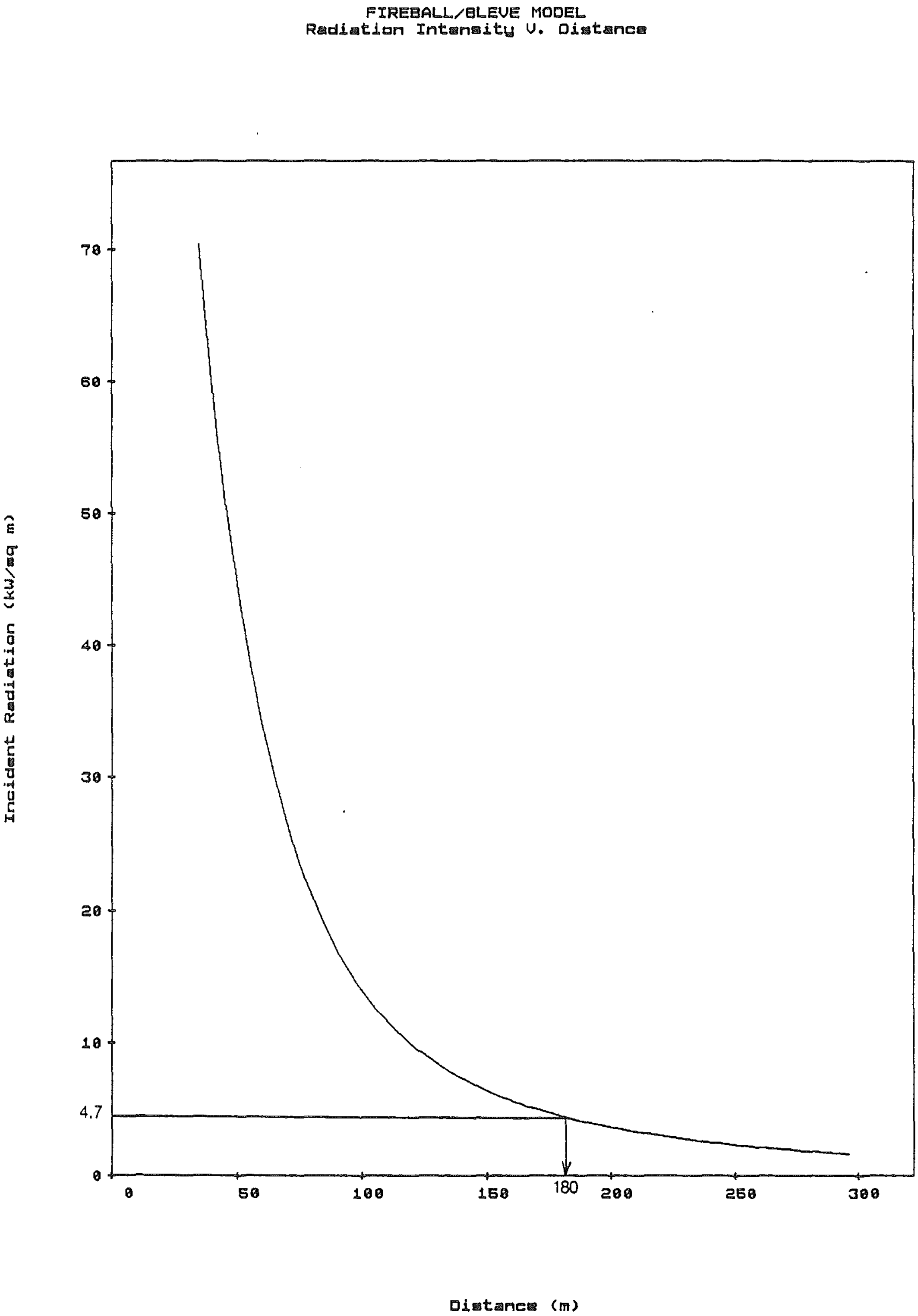
RESULTS

Maximum Radius of Fireball (m)	34.38
Duration Of Fireball (s)	5.335
Distance to 1.60 kW/m^2 (m)	269.0
Distance to 4.00 kW/m^2 (m)	189.2
Distance to 12.5 kW/m^2 (m)	106.0
Distance to 37.5 kW/m^2 (m)	56.11

Appendix 11 Whazan Results LPG (Propane)



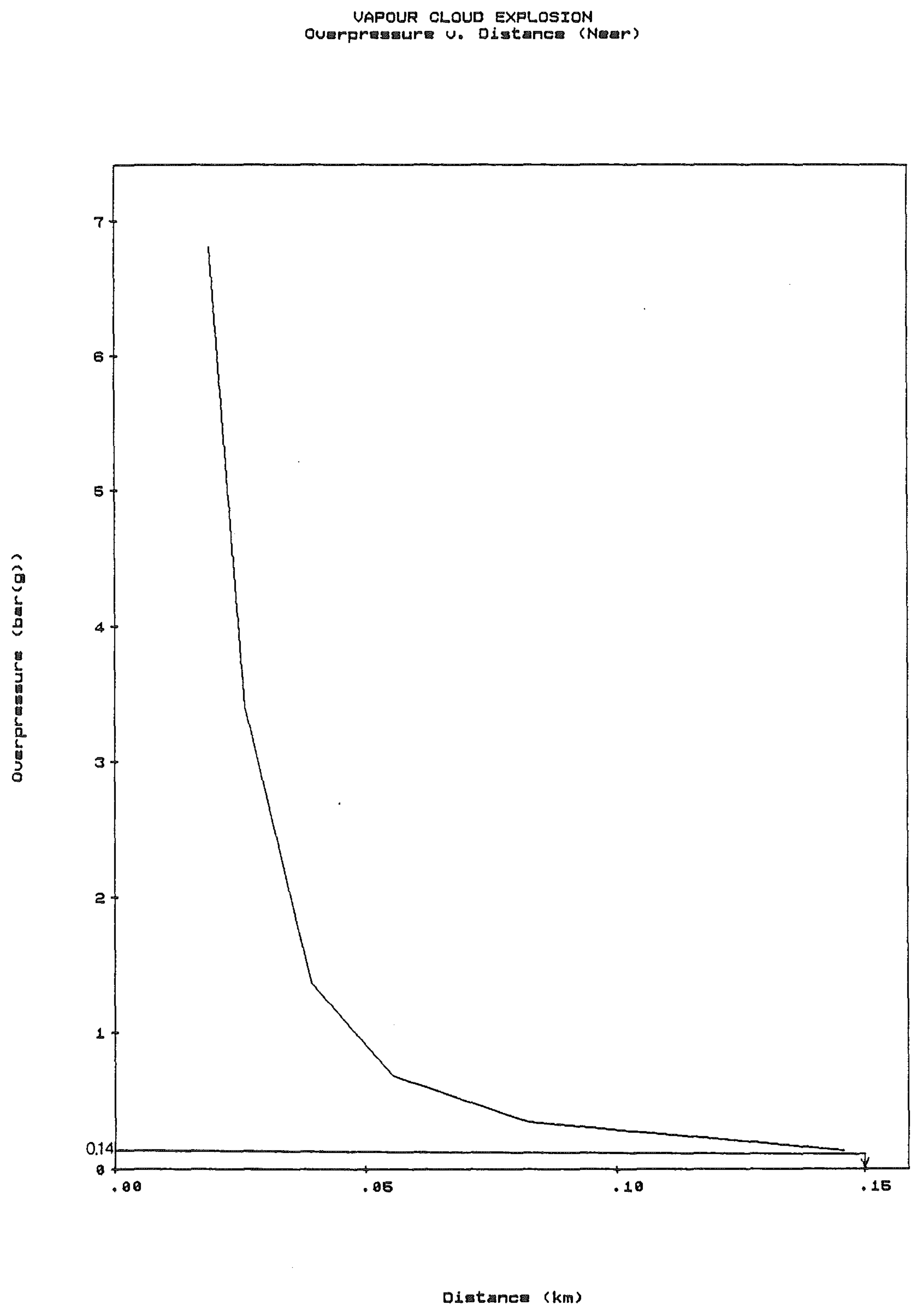
Appendix 11 Whazan Results LPG (Propane)



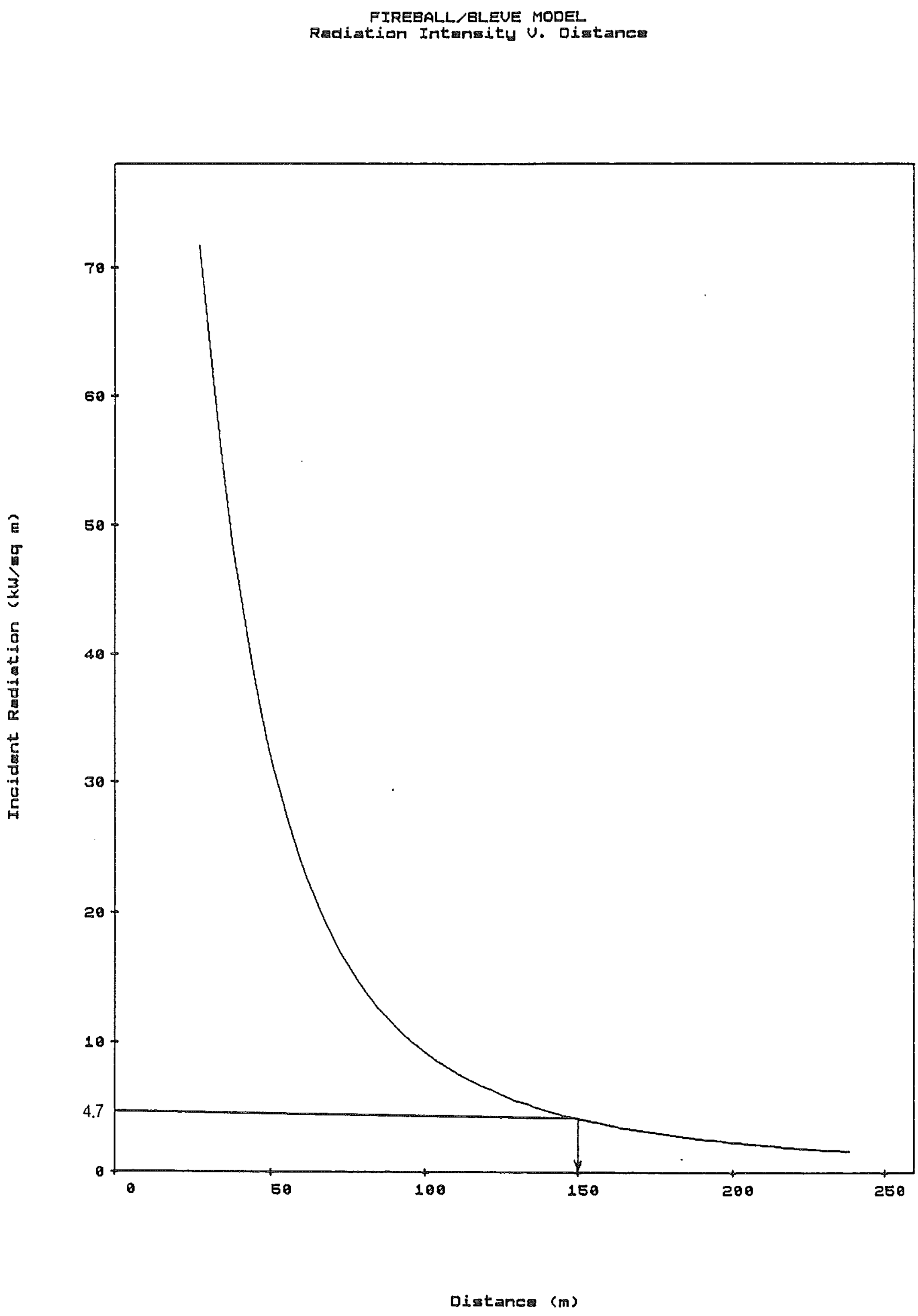
Fireball/ Bleve Model

Material	**Propane**
INPUT DATA	
Flammable Mass (kg)	833
Efficiency Factor	0.2000
RESULTS	
Maximum Radius of Fireball (m)	27.29
Duration Of Fireball (s)	4.234
Distance to 1.60 kW/m^2 (m)	237.4
Distance to 4.00 kW/m^2 (m)	151.7
Distance to 12.5 kW/m^2 (m)	85.03
Distance to 37.5 kW/m^2 (m)	45.10

Appendix 11 Whazan Results LPG (Propane)



Appendix 11 Whazan Results LPG (Propane)



Appendix 12. Software Listing - Management Factor Calculation

```
FOR i=1 TO 5
READ Des$(i):READ Rat(i)
NEXT
FOR j=1 TO 4:READ cl$(j):NEXT
wf=.5
tot=0

FOR j=1 TO 4:CLS
PRINT :PRINT :PRINT
PRINT "Considering ";cl$(j):PRINT :PRINT
GOSUB out
INPUT"Please enter code of descriptor";co(j)
tot=tot+Rat(co(j))
NEXT

IF tot=0 THEN tot=.1
mf=(1/(wf*tot))
PRINT :PRINT :PRINT "management factor =" ;mf
WHILE INKEY$<>" ":WEND
END

out:
PRINT "Code","Descriptor","Rating"
PRINT
FOR i=1 TO 5
```

```
PRINT i,Des$(i),Rat(i)
NEXT
PRINT :PRINT :PRINT
RETURN

DATA Poor,0,Fair,0.2,Average,0.5,Good
DATA 0.8,Excellent,1.0
DATA training,maintenance
DATA instrumentation
DATA safety management
```

Appendix 14. Dow Fire and Explosion Index Sheets

EXHIBIT A

FIRE AND EXPLOSION INDEX

LOCATION		DATE	
PLANT: Sulphuric Acid	PROCESS UNIT: LPG bullet	EVALUATED BY	REVIEWED BY

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT: Propane

STATE OF OPERATION: □ START-UP □ SHUT-DOWN □ NORMAL OPERATION

BASIC MATERIAL(S) FOR MATERIAL FACTOR

MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140°F) — 21

1. GENERAL PROCESS HAZARDS	PENALTY	PENALTY USED	
BASE FACTOR	1.00	1.00	
A. EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)			
B. ENDOTHERMIC PROCESSES (FACTOR .20 to .40)			
C. MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)	0.5	0.5	
D. ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)			
E. ACCESS	.35	0.35	
F. DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ______ Gals.		0.25	
GENERAL PROCESS HAZARDS FACTOR (F_1)		2.1	
2. SPECIAL PROCESS HAZARDS			
BASE FACTOR	1.00	1.00	
A. TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80)		0.2	
B. SUB-ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50		
C. OPERATION IN OR NEAR FLAMMABLE RANGE □ INERTED □ NOT INERTED			
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50		
2. PROCESS UPSET OR PURGE FAILURE	.30		
3. ALWAYS IN FLAMMABLE RANGE	.80		
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)			
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE 370 psig RELIEF SETTING 420 psig	$1.3 \times \frac{0.59}{0.62}$	× 0.58 =	0.71
F. LOW TEMPERATURE (FACTOR .20 to .30)		0.2	
G. QUANTITY OF FLAMMABLE/UNSTABLE MATERIAL: QUANTITY 22000 lbs., H_c = 19.9×10^3 BTU/lb			
1. LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)			
2. LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)		0.35	
3. COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)			
H. CORROSION AND EROSION (FACTOR .10 to .75)		0.2	
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)		0.1	
J. USE OF FIRED HEATERS (SEE FIG. 6)			
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)			
L. ROTATING EQUIPMENT	.50		
SPECIAL PROCESS HAZARDS FACTOR (F_2)		2.56	
UNIT HAZARD FACTOR ($F_1 \times F_2 = F_3$)		5.36	
FIRE AND EXPLOSION INDEX ($F_3 \times MF$ = F & EI)			112.9

FORM C-22380 R-4-87 (471-036)

Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

✓a) Emergency Power	.98	f) Inert Gas	.94 to .96
b) Cooling	.97 to .99	g) Operating Instructions/ Procedures	.91 to .99
✓c) Explosion Control	.84 to .98	h) Reactive Chemical Review	.91 to .98
d) Emergency Shutdown	.96 to .99		
e) Computer Control	.93 to .99		

C_1 Total 0·91 *

2. Material Isolation (C_2)

✓ a) Remote Control Valves	.96 to .98	c) Drainage	.91 to .97
b) Dump/Blowdown	.96 to .98	✓d) Interlock	.98

C_2 Total 0·96 *

3. Fire Protection (C_3)

(1·06 × 0·8 = 0·834)

a) Leak Detection	.94 to .98	✓ f) Sprinkler Systems	.74 to .97
b) Structural Steel	.95 to .98	g) Water Curtains	.97 to .98
c) Buried Tanks	.84 to .91	h) Foam	.92 to .97
d) Water Supply	.94 to .97	i) Hand Extinguishers/Monitors	.95 to .98
e) Special Systems	.91	j) Cable Protection	.94 to .98

C_3 Value 0·834 *

Credit Factor = $C_1 \times C_2 \times C_3$ = 0·73 Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1. F & EI	112·9		
A-2. Radius of Exposure	94.8 ft.		
A-3. Value of Area of Exposure		$MM	
B. Damage Factor			
C. Base MMPD (A-3 X B)		$MM	
D. Credit Factor	0·73		
E. Actual MMPD (C X D)		$MM	
F. Days Outage (MPDO)			da
G. Business Interruption Loss (BI)		$MM	

* Product of all factors used.

BACK OF FORM C-22380 R-4-87 (471-036)

Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT A

FIRE AND EXPLOSION INDEX

LOCATION	DATE

PLANT	PROCESS UNIT	EVALUATED BY	REVIEWED BY
Sulphuric Acid	Sulphur Melter		

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT: Sulphur, Hydrogen Sulphide

STATE OF OPERATION: ☐ START-UP ☐ SHUT-DOWN ☐ NORMAL OPERATION

BASIC MATERIAL(S) FOR MATERIAL FACTOR: Hydrogen Sulphide

MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140 F) → 21

1. GENERAL PROCESS HAZARDS	PENALTY	PENALTY USED
BASE FACTOR →	1.00	1.00
A. EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)		
B. ENDOTHERMIC PROCESSES (FACTOR .20 to .40)		
C. MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)		0.85
D. ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)	0.6	0.3
E. ACCESS	.35	
F. DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ______ Gals.		
GENERAL PROCESS HAZARDS FACTOR (F_1) →		2.15

2. SPECIAL PROCESS HAZARDS	PENALTY	PENALTY USED
BASE FACTOR →	1.00	1.00
A. TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80)		0.6
B. SUB-ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50	
C. OPERATION IN OR NEAR FLAMMABLE RANGE ☐ INERTED ☐ NOT INERTED		
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50	
2. PROCESS UPSET OR PURGE FAILURE	.30	0.3
3. ALWAYS IN FLAMMABLE RANGE	.80	
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)		
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE ______ psig RELIEF SETTING ______ psig		
F. LOW TEMPERATURE (FACTOR .20 to .30)		
G. QUANTITY OF FLAMMABLE/UNSTABLE MATERIAL: QUANTITY 20 lbs., H_c = 6.5×10^3 BTU/lb		
1. LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)		0.15
2. LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)		
3. COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)		
H. CORROSION AND EROSION (FACTOR .10 to .75)		0.5
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)		0.3
J. USE OF FIRED HEATERS (SEE FIG. 6)		
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)		
L. ROTATING EQUIPMENT (FAN)	.50	0.2
SPECIAL PROCESS HAZARDS FACTOR (F_2) →		3.05
UNIT HAZARD FACTOR ($F_1 \times F_2 = F_3$) →		6.5575

FIRE AND EXPLOSION INDEX ($F_3 \times MF$ = F & EI) → 137.7

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Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

✓ a) Emergency Power	.98	f) Inert Gas	.94 to .96
b) Cooling	.97 to .99	✓g) Operating Instructions/ Procedures	.91 to .99 (0.98)
c) Explosion Control	.84 to .98	h) Reactive Chemical Review	.91 to .98
d) Emergency Shutdown	.96 to .99		
e) Computer Control	.93 to .99		

C_1 Total 0.96 *

2. Material Isolation (C_2)

a) Remote Control Valves	.96 to .98	c) Drainage	.91 to .97
b) Dump/Blowdown	.96 to .98	d) Interlock	.98

C_2 Total ________ *

3. Fire Protection (C_3)

✓ a) Leak Detection	.94 to .98 (0.94)	f) Sprinkler Systems	.74 to .97
b) Structural Steel	.95 to .98	g) Water Curtains	.97 to .98
c) Buried Tanks	.84 to .91	h) Foam	.92 to .97
d) Water Supply	.94 to .97	✓i) Hand Extinguishers/Monitors	.95 to .98 (0.96)
e) Special Systems	.91	j) Cable Protection	.94 to .98

C_3 Value 0.90 *

Credit Factor = $C_1 \times C_2 \times C_3$ = 0.864 Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1.	F & EI	137.7	
A-2.	Radius of Exposure	115.7 ft.	
A-3.	Value of Area of Exposure		$MM ________
B.	Damage Factor	________	
C.	Base MMPD (A-3 X B)		$MM ________
D.	Credit Factor	0.864	
E.	Actual MMPD (C X D)		$MM ________
F.	Days Outage (MPDO)		________ da
G.	Business Interruption Loss (BI)		$MM ________

* Product of all factors used.

BACK OF FORM C-22380 R-4-87 (471-036)

Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT A

FIRE AND EXPLOSION INDEX

LOCATION	DATE

PLANT	PROCESS UNIT	EVALUATED BY	REVIEWED BY
Sulphuric Acid	Sulphur Burner		

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT

Sulphur Dioxide

STATE OF OPERATION	BASIC MATERIAL(S) FOR MATERIAL FACTOR
☐ START-UP ☐ SHUT-DOWN ☐ NORMAL OPERATION	

MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140 F)			1
1. GENERAL PROCESS HAZARDS	PENALTY	PENALTY USED	
BASE FACTOR	1.00	1.00	
A. EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)		0.5	
B. ENDOTHERMIC PROCESSES (FACTOR .20 to .40)			
C. MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)			
D. ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)			
E. ACCESS	.35		
F. DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ______ Gals.			
GENERAL PROCESS HAZARDS FACTOR (F_1)		1.5	
2. SPECIAL PROCESS HAZARDS			
BASE FACTOR	1.00	1.00	
A. TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80)		0.4	
B. SUB-ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50		
C. OPERATION IN OR NEAR FLAMMABLE RANGE ☐ INERTED ☐ NOT INERTED			
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50		
2. PROCESS UPSET OR PURGE FAILURE	.30		
3. ALWAYS IN FLAMMABLE RANGE	.80		
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)			
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE ______ psig RELIEF SETTING ______ psig			
F. LOW TEMPERATURE (FACTOR .20 to .30)			
G. QUANTITY OF FLAMMABLE/UNSTABLE MATERIAL: QUANTITY ______ lbs., H_C = ______ BTU/lb			
1. LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)			
2. LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)			
3. COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)			
H. CORROSION AND EROSION (FACTOR .10 to .75)		0.5	
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)		0.3	
J. USE OF FIRED HEATERS (SEE FIG. 6)			
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)			
L. ROTATING EQUIPMENT	.50		
SPECIAL PROCESS HAZARDS FACTOR (F_2)		2.2	
UNIT HAZARD FACTOR ($F_1 \times F_2 = F_3$)		3.3	
FIRE AND EXPLOSION INDEX ($F_3 \times MF$ = F & EI)			3.3

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Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

a) Emergency Power	.98	f) Inert Gas	.94 to .96
b) Cooling	.97 to .99	✓ g) Operating Instructions/ Procedures	.91 to .99 (0.95)
c) Explosion Control	.84 to .98	h) Reactive Chemical Review	.91 to .98
✓ d) Emergency Shutdown	.96 to .99 (0.97)		
e) Computer Control	.93 to .99		

C_1 Total 0.92 *

2. Material Isolation (C_2)

✓ a) Remote Control Valves	.96 to .98 (0.96)	c) Drainage	.91 to .97
b) Dump/Blowdown	.96 to .98	d) Interlock	.98

C_2 Total 0.96 *

3. Fire Protection (C_3)

✓ a) Leak Detection	.94 to .98 (0.95)	f) Sprinkler Systems	.74 to .97
✓ b) Structural Steel	.95 to .98 (0.96)	g) Water Curtains	.97 to .98
c) Buried Tanks	.84 to .91	h) Foam	.92 to .97
d) Water Supply	.94 to .97	i) Hand Extinguishers/Monitors	.95 to .98
e) Special Systems	.91	j) Cable Protection	.94 to .98

C_3 Value 0.912 *

Credit Factor = $C_1 \times C_2 \times C_3$ = 0.805 Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1. F & EI	3.3		
A-2. Radius of Exposure	2.772 ft.		
A-3. Value of Area of Exposure		$MM	
B. Damage Factor			
C. Base MMPD (A-3 X B)		$MM	
D. Credit Factor	0.805		
E. Actual MMPD (C X D)		$MM	
F. Days Outage (MPDO)			da
G. Business Interruption Loss (BI)		$MM	

* Product of all factors used.

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Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT A

FIRE AND EXPLOSION INDEX

LOCATION	DATE

PLANT	PROCESS UNIT	EVALUATED BY	REVIEWED BY
Sulphuric Acid	Acid Storage		

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT

Sulphuric Acid

STATE OF OPERATION

☐ START-UP ☐ SHUT-DOWN ☐ NORMAL OPERATION

BASIC MATERIAL(S) FOR MATERIAL FACTOR

MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140° F)			1
1. GENERAL PROCESS HAZARDS	PENALTY	PENALTY USED	
BASE FACTOR	1.00	1.00	
A. EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)		0.3	
B. ENDOTHERMIC PROCESSES (FACTOR .20 to .40)			
C. MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)			
D. ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)			
E. ACCESS	.35	0.35	
F. DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ______ Gals.			
GENERAL PROCESS HAZARDS FACTOR (F_1)		1.65	
2. SPECIAL PROCESS HAZARDS			
BASE FACTOR	1.00	1.00	
A. TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80)		0.4	
B. SUB-ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50		
C. OPERATION IN OR NEAR FLAMMABLE RANGE ☐ INERTED ☐ NOT INERTED			
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50		
2. PROCESS UPSET OR PURGE FAILURE	.30		
3. ALWAYS IN FLAMMABLE RANGE	.80		
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)			
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE ______ psig RELIEF SETTING ______ psig			
F. LOW TEMPERATURE (FACTOR .20 to .30)			
G. QUANTITY OF FLAMMABLE UNSTABLE MATERIAL: QUANTITY ______ lbs.. H_c = ______ BTU/lb			
1. LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)			
2. LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)			
3. COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)			
H. CORROSION AND EROSION (FACTOR .10 to .75)		0.5	
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)			
J. USE OF FIRED HEATERS (SEE FIG. 6)			
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)			
L. ROTATING EQUIPMENT	.50		
SPECIAL PROCESS HAZARDS FACTOR (F_2)		1.9	
UNIT HAZARD FACTOR ($F_1 \times F_2 = F_3$)		3.135	
FIRE AND EXPLOSION INDEX ($F_3 \times MF$ = F & EI)			3.135

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Appendix 14 Dow Fire and Explosion Index Sheets

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

a) Emergency Power	.98	f) Inert Gas	.94 to .96
b) Cooling	.97 to .99	g) Operating Instructions/ Procedures	.91 to .99
c) Explosion Control	.84 to .98		
d) Emergency Shutdown	.96 to .99	h) Reactive Chemical Review	.91 to .98
e) Computer Control	.93 to .99		

C_1 Total ________ *

2. Material Isolation (C_2)

a) Remote Control Valves	.96 to .98	c) Drainage	.91 to .97 (0·95)
b) Dump/Blowdown	.96 to .98	d) Interlock	.98

C_2 Total 0·95 *

3. Fire Protection (C_3)

a) Leak Detection	.94 to .98	f) Sprinkler Systems	.74 to .97
b) Structural Steel	.95 to .98	g) Water Curtains	.97 to .98
c) Buried Tanks	.84 to .91	h) Foam	.92 to .97
d) Water Supply	.94 to .97	i) Hand Extinguishers/Monitors	.95 to .98
e) Special Systems	.91	j) Cable Protection	.94 to .98

C_3 Value ________ *

Credit Factor = $C_1 \times C_2 \times C_3$ = 0·95 Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1. F & EI	3·5		
A-2. Radius of Exposure	2·63 ft.		
A-3. Value of Area of Exposure		$MM	
B. Damage Factor			
C. Base MMPD (A-3 X B)		$MM	
D. Credit Factor	0·95		
E. Actual MMPD (C X D)		$MM	
F. Days Outage (MPDO)			da
G. Business Interruption Loss (BI)		$MM	

* Product of all factors used.

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